COBRA

UNITED STATES MARINE CORPS COMPUTER-BASED RECRUIT ASSIGNMENT MODEL

FINAL TECHNICAL REPORT
AND USER'S GUIDE

DECISION SYSTEMS
DSA
ASSOCIATES, INC.

Prepared for:

MANPOWER RESEARCH AND
INFORMATION BRANCH,
G-1 DIVISION, U.S. MARINE CORPS

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COBRA

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COMPUTER-BASED RECRUIT ASSIGNMENT MODEL

FINAL TECHNICAL REPORT

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Prepared under

Contract Nonr-4070(00)
Office of Naval Research

Submitted by

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ACKNOWLEDGEMENTS

Over a five-year period, beginning in 1964, each of the four military services implemented computer-based recruit assignment systems. Three of the systems, the U.S. Marine Corps' COBRA system, the U.S. Army's ACT II system, and the U. S. Navy's COMPASS II system, were designed and programmed by Decision Systems Associates, Inc. as a direct result of the research effort described in this report. The project resulted from an unsolicited proposal submitted by the author while serving as a consultant to the Commander, U.S. Marine Corps Communications and Electronics School Battalion. It originated as a result of a close professional association with Dr. William J. Moonan, Director of Statistical Services, U.S. Navy Personnel Research Activity, San Diego. For his unflagging belief in the susceptibility of the problem to an optimal computer-based solution, and his contributions to such a solution, the author is deeply grateful. Dr. Robert Boldt, at that time investigating the problem for the U.S. Army Personnel Research Office, wisely advised the author to pursue the Ford-Fulkerson network flow approach. This advice was received at a time when an intensive investigation of a number of algorithms potentially applicable to the problem had proven most discouraging. John Wolfe, also of the U.S. Navy Personnel Research Activity, provided a key contribution to the system with his solution to the problem of controlling the distribution of shortages under conditions of infeasibility.

During development, implementation, and refinement of the COBRA system, a number of individuals within the Marine Corps assisted the project in one way or another. Colonel Arnold W. Harris, at that time Commanding Officer of the C&E School Battalion, patiently and farsightedly supported the earliest research efforts. At various stages in the project, four different generals approved and encouraged the research: Major General Bruno Hocmuth, Major General Ormond R. Simpson, Major General Raymond G. Davis, and Major General Jonas M. Platt. Enthusiastic promotion of the project and painstaking assistance to the contractor by the following manpower management officers proved invaluable to the success of the project: Colonel James K. Johnson; Colonel Harry Hunter, Jr.; Lt. Col. James W. Marsh; Lt. Col. Malcolm V. Fites; and Lt. Col. Jerry F. Mathis.

Finally, grateful appreciation is expressed to Lester R. Ford, Jr., and Delbert R. Fulkerson for their elegant and ingeniously efficient primal-dual network flow solution to the personnel assignment problem.

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I. INTRODUCTION

Since World War II, the continuous evolution of sophisticated weaponry has increased Marine Corps requirements for highly trained, technically competent personnel. At the same time, the armed services have faced increasing competition from academic, governmental, and industrial communities for both skilled and trainable personnel. As a consequence, it became increasingly essential that the USMC achieve maximum exploitation of the skills and talents available in the manpower pool.

A difficult problem faced personnel managers responsible for the utilization of new manpower resources. The critical point involved the decision process determining initial assignments to occupational training.

In 1964, Decision Systems Associates, Inc. initiated research to develop a computer-based mathematical model for optimal assignment of recruits. The first phase of the research project required development of large capacity, computationally efficient network flow algorithms. Subsequent phases entailed design, programming, and implementation of COBRA, the USMC Computer-Based Recruit Assignment system.

Implementation of the Marine Corps' COBRA system in the Spring of 1965 provided the first optimal recruit assignment system operational in the armed services.

II. PERSONNEL ASSIGNMENT RESEARCH

A. PROBLEM FORMULATION

It is convenient to depict the personnel assignment problem by a matrix in which each row represents a man and each column represents an assignment category. A quota is associated with each assignment category. Each row and column intersection defines a cell containing the value (productivity) of assigning the row to the column. It is possible, then, to construct a productivity or pay-off matrix by introducing the appropriate utility or pay-off value into each admissible cell of the matrix.[1] In the recruit assignment problem, the pay-off's are estimates of the probability of success of the recruit for each of the assignment categories. The Marine Corps administers the Army Area Aptitude Battery to all recruits, and then computes eight area aptitude composites from linear combinations of the basic tests in the aptitude battery. The area aptitude composites are then used to estimate each recruit's success in the many training opportunities.

Conceptually, it will also be helpful to consider a parallel matrix in which, at solution time, each final assignment will be represented by a cell entry of one at the appropriate row and column intersection. All other cells will contain zeroes. This is called a classification matrix.

The personnel assignment problem involves consideration of each individual's estimated proficiency in each assignment category relative to all alternative assignment possibilities for all individuals. An optimal solution entails identification of that combination of individual-by-job pairings (assignments) which produces the maximum total of estimated proficiencies, where only the proficiency of each individual in the category to which assigned is used in the total.

Optimality requires the determination of a zero-one classification matrix specifying an arrangement of assignments such that the trace of the product of this classification matrix by the transpose of the productivity matrix is a maximum.

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[1] It is important to recognize that some row-column intersections (assignments) may be inadmissible. In the assignment problem this occurs whenever the man (row) fails to meet minimum prerequisites associated with the assignment category (column).

A feasible solution is necessary to obtain an optimal solution. Feasible solutions may be obtained only if the following conditions hold true:

(1) Each individual is assigned full-time to one, and only one, job category; and

(2) The number of individuals assigned to each job category equals the quota for that category; and

(3) The sum of the quotas equals the number of men.

A precise statement of the personnel assignment problem is presented in Appendix A.

B. REVIEW OF THE LITERATURE

For approximately twenty-five years, researchers have been concerned with the problem of optimum utilization of personnel resources. Brogden (1946) stated the problem as one of devising a procedure "for maximizing efficiency of selection and assignment when each individual may be eligible for several assignments."

Methods for arriving at a set of assignments of men to jobs were described by Brogden (1946, 1954) and Dwyer (1954, 1957). Additional theoretical approaches bearing on this problem have been developed by Gass (1958), Ward (1959), and Ford and Fulkerson (1956). Unfortunately, as late as 1960 the capabilities of existing computers were such that solutions to the personnel assignment problem were not feasible (Horst, 1960). However, as increasingly sophisticated computers emerged, the development of a fully automated assignment system became possible.

Methods for solving the assignment problem optimally include both primal and primal-dual approaches. Primal methods include the earliest work by Hitchcock (1941) and Kantarovitch (1958), Dantzig's adaptation of the Simplex method (1963), and methods given by Beale (1959), Flood (1956), Balinski and Gomory (1964), and Klein (1967). Primal-dual methods include Kuhn's Hungarian method (1955), and two variants, one by Munkres (1957) and another by Ford and Fulkerson (1957), and methods by Busacker and Gowen (1965), Flood (1956), and Jewell (1962). Fulkerson's out-of-kilter algorithm (1961) is essentially a primal method.[2] Algorithms based on the Hungarian method are known to be superior to those

[2] All algorithms mentioned are concerned with linear costs (i.e., pay-offs). For convex costs, similar approaches have been developed by Menon (1965) (primal), and by Hu (1966) (primal-dual).

based on the Simplex method, which is not surprising considering that the assignment and transportation problems are very special cases of the more general linear programming problem.[3] After considerable experimentation and testing of algorithms, it was determined that the Ford-Fulkerson (1962) approach to linear integer network flow problems provided a primal-dual transportation algorithm which proved vastly superior to any of the alternative approaches available in the literature. The operational efficiency of the algorithm depends, of course, on the computer implementation. This is a result of the particular operations required: vector searching as opposed to the matrix operations required by the Simplex methods.

C. ACCOMMODATION OF PROBLEM SIZE

It was determined that a reasonable military assignment problem involved, at maximum, the assignment of 7500 men to 500 assignment categories — a problem requiring the solution to a matrix containing 3,750,000 cells! Any mathematically optimal approach to such a problem entails the examination of cell entries many millions of times in arriving at a solution. Obviously, such a solution would have to be carried out in high speed core to solve within a practical computation period.

Given a reasonable density and the published Ford-Fulkerson algorithms, it was not possible to solve a problem of this magnitude in core with even the largest scientific computers. It was, therefore, necessary to develop a unique approach which would provide in core solutions to multi-million cell matrices.

D. MATRIX ELIMINATION

An approach was developed which eliminated the necessity of storing, explicitly, a pay-off matrix directly addressable in core. This was accomplished by structuring the problem so that the matrix would be "available" implicitly, i.e., each element of the matrix could be computed from independent row and column parameters. Furthermore, a majority of these parameters could be expressed as binary variables, thereby permitting exploitation of

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3 Linear programming is the name given to a set of techniques for finding the extreme of a linear function of several variables when those variables are subject to linear constraints. The constraints are expressed either as equalities or inequalities governing the behavior of the variables in a linear way. The classical transportation problem is a special case insofar as each "basis" (i.e., any set of independent columns of the coefficient matrix in which the right-hand side can be uniquely expressed) is triangular as a result of the equality condition of total supply and demand. (Dantzig, 1963).

extremely efficient storage and computational techniques to solve the problem.

Again, implicitly, the problem was divided into two parallel matrices: an eligibility (constraint) matrix and a pay-off matrix. Ninety-six binary variables per man and 186 binary variables per column were used to derive the constraint matrix. On the CDC 3600 computer, this information required only two storage words per man and four storage words per column, as each variable could be represented by a single bit. Each element in the eligibility matrix could then be computed by a series of Boolean operations, and the computations could be performed on forty-eight bits simultaneously. Further, the structure of the problem permitted storage of all pay-offs for each man in two computer words regardless of the number of columns. If (and only if) a particular individual were found to be eligible for a particular category, his pay-off for that category would be generated. This required extensive modification of the basic network flow algorithm.

Using these techniques, any eight bit cell entry in the maximum-sized matrix — a matrix containing 30,000,000 bits — could be constructed from information packed into thirty-two thousand words of high speed core. Given this information in core, the solution could be obtained by repeated generation and discarding of cell entries, as needed by the algorithms, without reference to peripheral storage equipments.

III. CHARACTERISTICS OF THE RECRUIT ASSIGNMENT PROBLEM

The practical, applied nature of the recruit assignment task posed a number of difficult problems. Solutions to two such problems required the development of unique algorithms, an effort critical to the development of a successful model. The highly specialized algorithms are employed by the COBRA model for feasibility finding and the optimization of multiple objectives. The development of an algorithm to optimize aptitude composites was originally plagued by matrix size accommodation problems (see Section II, D). Once the matrix was eliminated from core, design of the OPTIMIZE algorithm was straight-forward.

A. FEASIBILITY DETERMINATION

The recruit assignment problem is seldom initially feasible. One major reason for this involves the fact that many training quotas are generated long before information is available on the recruit pool. Infeasibility occurs whenever the quality and quantity of available recruits cannot be precisely accommodated by the mix of training quotas and their associated prerequisites. Consequently, it is necessary either to adjust quotas or eliminate unassigned men, or both, to achieve feasibility. Most important, an acceptable solution to the feasibility (quota adjustment) problem requires the capture and implementation of user policies regarding the relative importance of meeting quotas for the various training categories.

B. DESIGN OF THE QUOTFIND ALGORITHM

A powerful algorithm, QUOTFIND, was developed to solve the problem of infeasibility, and to insure maximum quota accommodation.

QUOTFIND permits specification of absolute quota-fill priorities for assignment categories. The use of absolute priorities forces the algorithm to attempt to fill high priority quotas regardless of the consequences to lower priority quotas. On the other hand, if a shortage of qualified recruits occurs for assignment categories with identical priorities, the QUOTFIND algorithm accommodates user specified sharing policies through the application of a non-linear optimization solution. This solution employs the method of Lagrange multipliers in conjunction with a Newton-Raphson iteration technique. These mathematical algorithms were incorporated with modified maximum flow algorithms to seek feasibility under the influence of column oriented controls called sharing coefficients.

QUOTFIND will maximize the fill of all quotas in accordance with absolute priorities and sharing coefficients, and each assignment category will have assigned to it recruits whose qualifications satisfy or exceed specified mandatory prerequisites for the category.

The QUOTFIND algorithm never increases a quota, and will lower the quota only when, under the policies, it cannot be filled by available talent. Within the same absolute priority level, quota reductions, when necessary, will be distributed equally among assignment categories of equal importance and unequally among those of unequal importance. This combination of feasibility finding algorithms permits precise control over the conversion of a set of infeasible quotas to the most desirable set of feasible quotas. The algorithm is essential because it provides a feasible basis for subsequent optimizations.

A technical description of QUOTFIND may be found in Appendix D.

C. MULTIPLE POLICY ACCOMMODATION

An acceptable solution to the recruit assignment problem must accommodate multiple, usually conflicting, assignment policies. For example, it is necessary to maximize, simultaneously, adherence to a large number of assignment policies of the following type in arriving at an acceptable assignment outcome:

— Maximize accommodation of recruit preference,

— Minimize relocation costs associated with assignments,

— Maximize the proportion of formal school assignees with desirable educational backgrounds,

— Maximize the proportion of formal school assignees possessing four year enlistment obligations,

— Etc.

D. DESIGN OF FEASFIND ALGORITHM

An algorithm, FEASFIND, was designed to solve the problem of multiple policy accommodation. In FEASFIND, successive surface optimizations are carried out to accommodate, simultaneously, the several assignment goals implied by Marine Corps assignment policy configurations.

The approach requires policies to be specified in terms of sets of desirable prerequisites for each assignment category. Once specified, the several sets of desirable prerequisites are then ordered into hierarchical levels for each assignment category. Importantly, different policy configurations may be structured for each assignment category.

FEASFIND solves the problem by finding feasible "subquotas" for each of the ordered desirable prerequisite levels. The objective of FEASFIND is to maximize the subquotas associated with the highest prerequisite levels for each assignment category. It must accomplish this while guaranteeing that the sum of the subquotas for each category equals the QUOTFIND derived quota. Further, the algorithm permits a priority ordering of categories so that the order in which maximization of policies takes place can be precisely controlled by the user.

To give an example, if one of the policies were to maximize the assignment to formal schools of recruits with a high school education, the user would structure this prerequisite into a desirable prerequisite level for each formal school category. He might also assign higher priorities to formal schools than to other categories. This would result in a corresponding disproportionate distribution of recruits with high school diplomas. The FEASFIND algorithm is concerned only with improvements in the "fit" of assignments, the "fill" having been obtained by QUOTFIND. Whenever different FEASFIND priorities are accorded each assignment category, a mathematically optimal accommodation of all policies is assured.

A technical description of FEASFIND appears in Appendix E.

E. APTITUDE MAXIMIZATION

As stated earlier, maximum utilization of talent is based on aptitude composites which are estimates of the probability of success of each recruit in each assignment category. An optimal solution to the problem demands an arrangement of assignments in which the sum of selection relevant aptitude composites is a maximum.

The OPTIMIZE algorithm was designed to obtain this optimum. The solution, however, is constrained by the QUOTFIND and FEASFIND solutions. While the QUOTFIND and FEASFIND algorithms maximize the quality of the overall solution from the standpoint of quota fill and policy accommodation, the OPTIMIZE algorithm maximizes the quality of the overall solution by rearranging assignments, where possible, to insure allocation of recruits to training categories for which they have the most aptitude. In so doing, it maximizes the probability of success of each recruit in his ultimate assignment.

A technical discussion of OPTIMIZE appears in Appendix F.

IV. COBRA SYSTEM DESCRIPTION

Solutions to the major problems of feasibility finding, multiple policy accommodation, and problem size permitted design and development of the COBRA system.

The three major algorithms already discussed, QUOTFIND, FEASFIND and OPTIMIZE, were integrated into a single-submission system. Their employment entails a series of optimizations, each of which progressively constrains subsequent optimizations. In each solution phase, all individuals are considered simultaneously. Any and all previous assignments may be altered, subject to constraints, to improve subsequent optimizations. A description of the sequence of operations performed by the system follows.

The first algorithm, QUOTFIND, determines a feasible set of quotas for the problem, structuring the fill of the quotas according to a specified policy. QUOTFIND considers three input parameters for each assignment category: a priority, a share coefficient, and the mandatory prerequisite level. The mandatory prerequisite level specifies the recruit qualification which must be present for assignment to the category. The priorities and share coefficients express fill distribution policy in the event infeasibility results from the talent mix characterizing the recruit pool. The QUOTFIND solution provides a feasible set of quotas which automatically replace the original quotas whenever this original set of quotas proves to be infeasible.

Once a feasible quota structure has been obtained by QUOTFIND, the FEASFIND and OPTIMIZE algorithms are called to arrive at the best fit of available talent within these quota constraints. FEASFIND improves the talent fit by maximizing the number of trainees that will be assigned to the highest prerequisite levels in each assignment category. This algorithm accepts another set of priorities which, if desired, can be completely independent of those specified for QUOTFIND. The FEASFIND priorities allow the user to order the assignment categories in terms of the importance of meeting desirable prerequisites, given a shortage of desirably qualified recruits. Such a shortage is universal in the military assignment problem. FEASFIND first maximizes the number of recruits assigned to the highest desirable prerequisite level of the highest priority assignment category. If the quota cannot be filled with level one qualified recruits, FEASFIND automatically relaxes to the second highest prerequisite level and then maximizes the number of recruits assigned at this prerequisite level without changing the number of level one assignments. If necessary, level three assignments are maximized while preserving the number of level one and level two assignments, respectively, and so on. This "relaxation of levels" operation alternates with the maximization solution until the total number of recruits assigned to the category equals the quota. The entire process progresses from one assignment category to the next in priority order with the results of all previous optimizations preserved in all subsequent optimizations. When the FEASFIND solution is completed, the exact number of individuals that can be assigned on each prerequisite level in each assignment category is known and passed on to the OPTIMIZE algorithm. Each recruit has a tentative assignment, but the assignment may be altered in the OPTIMIZE solution.

The OPTIMIZE algorithm maximizes the sum of selection relevant aptitude composites without modifying either the quotas determined by QUOTFIND or the numbers of recruits to be assigned at each prerequisite level as determined by FEASFIND. When OPTIMIZE terminates, every quota has been filled, the maximum number of recruits have been assigned at the highest prerequisite levels, and the average probability of success in training, as estimated by selection relevant aptitude composites, is at a maximum.

One important system component merits brief discussion. The Dictionary Preparation Program (PREDICT) was developed to minimize, insofar as possible, the key-punching and verification effort required to supply the COBRA system with information concerning assignment categories for a particular run. PREDICT enables the user to store on tape a "Dictionary" file of all possible assignment categories. The data includes all prerequisites, both mandatory and desired, for every possible USMC assignment category, the FEASFIND priority, and the selection relevant aptitude composite associated with the category. Given the Dictionary, the volume of information needed to operate the COBRA system is drastically reduced.

V. EVALUATION

There are many possible criteria of system effectiveness. For example, are maximization solutions optimal or approximately optimal? Does the system fully accommodate all assignment objectives? How do solutions obtained by the new system compare with solutions obtained from the system to be replaced? As the number of criteria, though finite, would be too large to examine exhaustively in this report, it was decided to limit the evaluation to quality comparisons between the manual system to be replaced and the COBRA system. Assignment quality was defined by these three factors:

(1) Quota accommodation,

(2) Accommodation of desirable (as opposed to mandatory) assignment prerequisites, and

(3) The average proficiency estimate of all recruits in the training category to which assigned.

Evaluation of the above factors required an extensive series of computer solutions. The available data consisted of manual solutions carried out in previous months. Computer and manual assignment results were compared for recruits assigned at MCRD—San Diego, for each of the months from May through November of 1964.

In structuring these comparisons between computer and manual assignment solutions, it was not possible to arrive at the original quotas. Consequently, the quota fill achieved by assignment technicians was used as the original quota for the COBRA solutions. This eliminated the possibility of comparing quota fill for the two approaches, but provided the most legitimate possible "fit" comparisons between the two approaches.

A. ACCOMMODATION OF DESIRABLE PREREQUISITES

Although mandatory prerequisites are specified for all assignment categories, desirable prerequisite levels may not be. Therefore, the comparison of manual with COBRA outcomes relating to desirable prerequisites was limited to assignment categories for which at least one desirable prerequisite level (over and above the mandatory level) had been specified. It should be recognized that all recruits satisfied mandatory prerequisites for all quotas. Results for the seven month period appear in Table #1.

TABLE #1

ACCOMMODATION OF DESIRABLE ASSIGNMENT PREREQUISITES

COMPARISON OF MANUAL VS. COMPUTER SOLUTIONS

Assignment Month (1964)	Number of Recruits Assigned*	Per Cent of Assignments Which Satisfied Desirable Restrictions	
		MANUAL SOLUTION	COMPUTER SOLUTION
May	926	48.6%	80.6%
June	1098	87.8%	89.4%
July	679	75.3%	87.3%
August	697	59.4%	79.3%
September	1587	82.4%	100.0%
October	711	78.6%	100.0%
November	971	58.8%	91.2%

* Analysis is limited to assignment categories possessing desirable assignment prerequisites.

For each month studied, the COBRA solution arrived at a higher percentage of desirably qualified recruit assignments. The magnitude of improvement in solution quality is substantial.

In the months of September and October, all COBRA assigned recruits met the desirable prerequisites associated with the training to which they were assigned. This result was possible because of the superior talent available in the recruit pool during these particular months. It is not surprising to note that, in spite of available talent, the manual solution resulted in a failure to accommodate desirable prerequisites. The problem is a particularly difficult one; the FEASFIND algorithm makes hundreds of millions of trial assignments in arriving at a solution. Obviously, such a problem is well beyond human search and trial capabilities.

B. SELECTION-RELEVANT APTITUDE COMPOSITE MAXIMIZATION

Assignment of recruits to each category was based on one of the aptitude composites — a composite presumably most predictive of success for that assignment category. Therefore, a comparison between manual and computer solutions required computation of the average of selection relevant aptitude composites, separately, for the two approaches. Results for the seven month comparison period appear below.

TABLE #2

APTITUDE OPTIMIZATION

COMPARISON OF MANUAL VS. COMPUTER SOLUTIONS

Assignment Month (1964)	Total Recruits Assigned*	Average of Aptitude Composites (Aptitude Scores) MANUAL SOLUTION	COMPUTER SOLUTION
May	1382	110.68	116.06
June	1140	108.89	112.72
July	850	112.16	118.36
August	1116	112.92	119.32
September	2450	112.04	119.01
October	1420	113.66	118.13
November	1447	113.14	120.29

* Analysis includes all assignment categories.

For each month studied, the COBRA solution provided a substantially higher average of selection relevant aptitude composites. These comparisons are based on COBRA optimizations unconstrained by a FEASFIND optimization. It is instructive to note that the improvements over the manual solutions were maintained even when the OPTIMIZE solution was constrained by a FEASFIND optimization to accommodate desirable assignment prerequisites. As expected, however, the FEASFIND solution served to reduce the

OPTIMIZE solution to some degree. Overall, the OPTIMIZE solutions dropped approximately one and one-half points. In spite of this, selection relevant aptitude composite averages three to five points higher than the manual solution averages were achieved by the COBRA system. The aptitude composite averages for the seven months studied were 113.46, 112.48, 117.26, 117.60, 117.34, 116.66, and 118.82, respectively, when FEASFIND solutions preceded, and therefore constrained, the OPTIMIZE solutions. This, of course, is the normal system application.

The foregoing findings demonstrate that the COBRA solutions provide substantial improvements — improvements of a practical magnitude — over solutions obtained from manual procedures. As expected, they also indicate that utilization of recruit aptitudes is decreased somewhat due to accommodation of desirable prerequisites. This information, available for the first time with the COBRA system, enables USMC manpower managers to "game" with the consequences of introducing new assignment policies prior to implementation. Appropriate trade-off decisions can then be made in terms of losses in recruit aptitude utilization.

APPENDIX A

TECHNICAL DISCUSSION OF THE PERSONNEL ASSIGNMENT PROBLEM

The personnel-assignment problem may be stated as follows:

Let c_{ij} = the proficiency of individual "i" when assigned to job (school) category "j",
where $i = 1, 2, \ldots, I$ = number of individuals
and $j = 1, 2, \ldots, J$ = number of job categories

The productivity or proficiency matrix consists of J different estimates of proficiency for each of the I individuals to be assigned. There will exist, then IJ c_{ij}'s. The proficiency measure may be a rating or prediction of success, but typically involves some linear combination of test scores derived by regression methods. It is probably most helpful to consider the c_{ij} as an aptitude index. In any case, once obtained, the c_{ij}'s must reflect the relative value to the total organization of each individual in every job category. For this reason, the productivity matrix is often called a payoff matrix. A trade-off of individuals between jobs will take place as a direct result of the relative values of the c_{ij}'s. Determination of these trade-off values presents a major problem in personnel-assignment research.

Individuals will be assigned in accordance with the following restrictions:

Let a_{ij} = the coefficient of classification associated with the assignment of individual "i" to job "j"; one if assigned, zero if unassigned.

$a_{ij} = 0$ or 1, (restriction 1)

and $\sum_{j}^{J} a_{ij} = 1$ for all i (restriction 2)

Together, the two restrictions require that no individual be unassigned or assigned to more than one job, and that all assignments to a job be full time.

Let q_j = quota of individuals to be assigned to job category "j".

$\sum_{j}^{J} q_j = I,$ (restriction 3)

$\sum_{i}^{I} a_{ij} = q_j$ (restriction 4)

The first equation simply states that the sum of all job category quotas equals the number of individuals to be assigned. The second equation requires that the number of individuals assigned to job category "j" equal the quota, q_j.

APPENDIX

The personnel-assignment problem involves the evaluation of each individual's estimated proficiency in each job category relative to all alternative assignment possibilities for all individuals. The solution entails identification of that combination of individual-by-job pairings (assignments) which will produce the maximum total of estimated proficiencies (c_{ij}'s).

This is accomplished by finding a zero-one classification matrix specifying the I optimal assignments such that the trace of the product of this classification matrix by the transpose of the c_{ij} (productivity) matrix is a maximum.

In linear programming terminology, the problem requires the assignment of I individuals to the J job categories such that some objective function, for example

$$\sum_{i}^{I} \sum_{j}^{J} c_{ij} \quad a_{ij}$$

is maximum under the four restrictions specified above. Some other objective function such as the minimum c_{ij} in each job category or the median c_{ij} for each job category might be also maximized.

APPENDIX B

DICTIONARY FILE — PREDICT

The COBRA Dictionary File contains information which controls virtually all of the policies implemented by the assignment system. It is, therefore, imperative that it be utilized and maintained properly if satisfactory assignments are to be achieved. It is equally important that the user be aware of the options which may be exercised through the Dictionary, as well as the kinds of errors that may occur. Two types of information, School Header and Restriction Level (prerequisite) information, control the assignment policies for each assignment category on the Dictionary Tape. Assignment-relevant School Header information consists of the assignment symbol, FEASFIND priority and designation of the selection-relevant area aptitude test associated with the training. Although it would be possible to specify legitimate but incorrect values for these parameters, such errors occur only rarely and are relatively easy to detect from the Dictionary reports.

The mandatory and desirable prerequisite levels (Restriction Level Card) available for each assignment category provide one of the most flexible and powerful management controls with which the user may structure assignment policy. In normal usage, the user must decide which prerequisites or combination of prerequisites are desirable for a particular type of training. These must then be ordered from the most desirable level to the mandatory or minimum acceptable level. Using the resulting set of levels, COBRA can optimally assign trainees against prerequisites which reflect a particular configuration of many policies. Incorrect, inconsistent or illogical specification of level information, however, may influence training assignment in subtle and undesirable ways.

The following principles will aid the user in avoiding specification errors:

1. The individual properties in a level are "ANDED" together; never "ORED." For example, if the properties Citizen and GT 120+ occur in the same level, any trainee assigned at that level would have to have a GT score greater than or equal to 120 <u>and</u> be a citizen.

2. COBRA treats all properties as though they were logically independent and allows any combination of properties to be specified in a level. The user must realize that some properties are not logically independent and that certain properties cannot be used on the same level. For example, if the properties MG4A and MG4B were used on the same level, no assignments could be made at that level since it is impossible for a trainee to be simultaneously classified into two different mental ability groups. If these properties were specified simultaneously at the mandatory level for some assignment category, no assignments could be made to it. Other examples of the simultaneous use of logically connected properties are not so disastrous but may be quite confusing, e.g., if the properties MM = 80+ and MM = 90+ appear on the same level, the MM = 90+ property takes precedence since any trainee who has an MM score greater than or equal to 90 has an MM score greater than 80. Therefore, in this instance no untoward assignment results would occur but the Dictionary reports would be confusing.

3. COBRA treats all levels as though they were independent. Therefore, the user <u>must</u> assure that the mandatory level in each assignment category is logically reflected in each desirable <u>level of</u> the assignment category. The desirable levels of an assignment category may be specified independently of one another, but <u>all</u> desirable levels must logically contain the mandatory level. Specifically, every trainee who is qualified <u>at</u> some desirable level in an assignment category must also be qualified at the mandatory level of that category. Note that this does not necessarily mean that the same properties must be specified in both the mandatory and desirable levels. For example, if the mandatory level for some assignment category contained an MM = 80+ property, desirable levels could contain an MM = 90+ property without ambiguity. If the reverse were true and the MM = 90+ appeared on the mandatory level while the MM = 80+ appeared on the desirable level, the desirable level would be less restrictive than the mandatory. Since such a specification is inherently illogical, the QUOTFIND and FEASFIND models might produce unsatisfactory assignment results which could be extremely difficult to detect.

APPENDIX C

MAXFLOW AND TRANSFER ALGORITHMS

1. MAXFLOW Algorithm

a. The task of assigning men to a collection of categories demanding specified quotas and having different eligibility requirements may be accomplished by means of the MAXFLOW algorithm. A man may be eligible for any set of categories but may only be assigned to one of the categories for which he is eligible. MAXFLOW takes advantage of these multiple eligibilities to assign the greatest number of men possible without exceeding quota limitations. Most other assignment algorithms use a scheme of weighted eligibilities whereby it is not possible to specify absolute ineligibility. Another advantage of MAXFLOW is the ability to identify where infeasibilities exist in the system. MAXFLOW is a specialized version of a network flow algorithm developed by Ford and Fulkerson.

b. To begin with MAXFLOW attempts to assign each man to a category for which he is eligible and in which there is a vacancy. If at the end of this process all quotas have been filled or no unassigned man is eligible for any category, then the assignment is complete. This is the trivial case for the assignment problem. In general, there will still remain unassigned men who are eligible only for categories which are already full, and there will be assigned men who are eligible for other unfilled categories. In this case MAXFLOW is required to move men out of filled categories into unfilled ones in order to leave vacancies for men who are presently unassigned. A man is never moved into a category for which he is not eligible and he is never moved out of a category unless there is another man eligible to take his place. No man once assigned to any category will ever be returned to the unassigned pool.

c. To assist in the understanding of the MAXFLOW process, the concept of a chain is introduced. A chain is a sequence of the form: man_1, category_2, man_2, category_3, man_3, ..., category_{n-1}, man_{n-1}, category_n; where

man_1 is unassigned

man_k is assigned to category_k, $k \geq 2$

man_k is eligible for category_{k+1}, $k \geq 1$

category_k is full, $k < n$

category_n has a vacancy

Man_1 is called the "origin" and category_n is called e "terminus". The men and categories appearing in a chain are called links. No two links are identical.

d. At each iteration MAXFLOW identifies those categories which are the termini of chains of minimal length (or indicates that no chains exist). One chain is associated with each such terminus. A flow takes place along one of these chains, i.e., man_{n-1} is reassigned to category_n, man_{n-2} is reassigned to category_{n-1}, ..., man_1 is assigned to category_2. The net effect of such a flow is to assign one more man. A flow occurs along each of the other minimal length chains as long as such a chain does not intersect one along which a flow has already been achieved. When all possible flows have been made, a new iteration is begun. When there are no chains left in the system, the assignment is complete. The proof of the previous statement will be presented after a discussion of the labeling process.

e. It would be extremely time consuming to trace through each possible chain in the system attempting to identify actual chains. Instead MAXFLOW identifies all men who are possible first links in chains, next, all categories which are possible third links, etc. MAXFLOW labels each possible link at the time that it is identified. Labeling is accomplished as follows:

— first, MAXFLOW labels unassigned men;
— next, it labels any category for which an unassigned man is eligible;
— then it labels any man who is assigned to a labeled category;
— next, it labels any unlabeled category for which a newly labeled man is eligible, etc.

A category is always labeled with the index of an eligible man. This process continues until:

(1) a category with a vacancy is labeled (in which case MAXFLOW finishes the labeling of all categories on this pass, but does not label any more men), or

(2) no more labeling is possible.

In case 1, chain flows may take place as described above since category_n is labeled with the index of man_{n-1}, who in turn is assigned to category_{n-1}, which is labeled with the index of man_{n-2}, etc. In case 2, the assignment is complete, which we may see as follows: No labeled man is eligible for any unlabeled category (otherwise the category would be labeled). Thus, only unlabeled men are eligible for unlabeled categories. These unlabeled men are already assigned to unlabeled categories. Hence, as many men as possible are assigned to labeled categories. Therefore, the maximum number of men have been assigned.

f. In detail MAXFLOW works as follows:

Step 1. All unassigned men are labeled.

Step 2. Any unlabeled category which has a labeled man eligible for it is labeled with the index of the man.

Step 3. If no category was labeled in the last pass through Step 2, then the assignment is complete, so terminate.

Step 4. If a category with a vacancy was labeled in Step 2, go to Step 6 to achieve a flow. If every labeled category is full, go to Step 5.

Step 5. Label each man in every category which was labeled in Step 2. Go to Step 2.

Step 6. A category with a vacancy has been labeled. This category will now be the terminus of a chain flow as follows:

Category$_n$ has a vacancy and is labeled with the index of man$_{n-1}$. Reassign man$_{n-1}$ to category$_n$. Man$_{n-1}$ was assigned to category$_{n-1}$ which now has a vacancy so man$_{n-2}$ may be moved into category$_{n-1}$. Repeat this procedure until man$_1$ is assigned to category$_2$. Erase the label of every category in this chain and of every man presently assigned to one of these categories.

Step 7. If no other labeled category has a vacancy, then erase all labels and go to Step 1.

Step 8. A labeled category has a vacancy. Trace backwards to see if this category is the terminus of a chain of labeled men and categories which originates with an unassigned man. If such a chain exists, go to Step 6 to achieve a flow. Otherwise erase the label of this category and of the men currently assigned to it. Go to Step 7.

g. Upon termination of MAXFLOW in Step 3, the set of categories is split into a labeled subset and an unlabeled subset. The men are of three types: (1) unassigned, (2) assigned to labeled categories and (3) assigned to unlabeled categories. Types 1 and 2 are called labeled men and type 3, unlabeled men. Only unlabeled men are eligible for unlabeled categories. An unlabeled category may or may not be full, whereas the labeled categories are all full. There are, in fact, an excess of men eligible for the set of labeled categories.

2. TRANSFER Algorithm

a. TRANSFER, a variant of the MAXFLOW algorithm, deals with the problem of adjusting imbalances in a given assignment of men to categories. As with MAXFLOW there is given a collection of categories, each with its own quota and eligibility requirements, and a collection of men, each of whom may be eligible for any of the categories. TRANSFER begins with men already assigned to categories. (It ignores those men who are unassigned.) The initial assignment is such that the categories are divided into three classes: (1) those whose quotas are not met, (2) those whose quotas are exactly met and (3) those whose quotas are exceeded. TRANSFER causes flows along chains which originate with men in overfilled categories and terminate in categories with vacancies.

b. TRANSFER employs a labeling procedure very similar to MAXFLOW's. The exceptions are: (1) that the labeling begins with all categories which have an excess of men instead of with the unassigned men and (2) that subsequently no category with an excess may be labeled.

APPENDIX D

QUOTFIND ALGORITHM

1. General

a. In the event that there are not enough men qualified at the mandatory level to meet the original assignment category (AC) quotas, the total deficit must be shared among the AC's in some reasonable manner. This is the function of the QUOTFIND algorithm. QUOTFIND reduces the individual AC quotas, in accordance with policies established by input parameters, so that the reduced quotas can all be met and the same number of men assignable under the original quotas are assignable under the reduced quotas. The process can be described as one of fitting the quotas to the available talent pool.

b. The quota reduction policies for an assignment pass are determined by two sets of constants. The first set assigns each AC to a priority group. These groups are processed sequentially, with AC quotas in high priority groups being filled as much as possible before an attempt is made to fill quotas in lower groups. The second set of constants are "share coefficients" which represent the weighting factor applied to the differential value associated with assigning a man to a particular AC. The exact mathematical formulations used are presented in paragraph 3. In general, if a given category's share coefficient is large with respect to other share coefficients in its priority group, the ratio of its reduced quota to original quota will be larger than such ratios for the other AC's.

c. QUOTFIND is an iterative model which assigns men, adjusts quotas, reassigns men, readjusts quotas, etc. The process terminates when the sharing policies have been met as well as possible. QUOTFIND is composed of four major sections: QF, MAXFLOW, TRANSFER, and FQF. QF is the control section and FQF performs the actual quota reduction. MAXFLOW and TRANSFER have already been discussed in Appendix C, and QF calls upon these routines to assign men and indicate where quota adjustments are necessary.

d. QUOTFIND can logically be separated into three processes:

— an assignment or reassignment process,
— a partitioning process, and
— a quota adjustment process.

These all go under the general heading of the "shredding" process, which is described next.

e. At the onset of the shredding process, QF has assigned as many men as possible into a given set of AC's, but has not been able to find enough qualified men to meet all of the quotas. At this point the quotas on the individual AC's in the set will be adjusted so that the set's total quota equals the total number of men assigned into the set. The result of this process is that some categories are left overfilled and others deficient. The men must now be reassigned in an attempt to conform to these new quotas. However, in this reassignment process no man must be left unassigned; hence, after the reapportionment attempt, some AC's may still be filled beyond their adjusted quotas. In the event that all quotas are actually met, processing terminates for this set of categories. Otherwise, the set is partitioned into two subsets:

- Subset (1) contains all AC's whose adjusted quotas are exceeded
- Subset (2) contains all AC's whose quotas are not met.

The AC's whose quotas are exactly met may be put in either of the subsets depending on the following criterion: No man assigned to an AC in Subset (1) should be eligible for any AC in Subset (2). The quotas for categories in Subset (2) are now adjusted so that the total of all quotas within the subset is equal to the number of men assigned into that subset. Reassignment within Subset (2) and partitioning of this subset, if necessary, now proceeds as with the original set. This recursive procedure terminates for a particular subset when the adjusted quotas for that subset are met. When a subset of type (2) is completely processed, the complementary subset of type (1) is then treated in the same manner. Since there were a finite number of AC's in the original set, processing is guaranteed to terminate with all adjusted quotas met.

2. QF

a. To simplify the description of QF, let us assume for the time being that all AC's are in the same priority level, since multiple priorities complicate the procedure, as will be explained later. QF first calls MAXFLOW to assign as many men as possible without exceeding quotas. If all quotas have been met, then processing terminates. Otherwise, upon return from MAXFLOW the schools are separated into labeled and unlabeled groups. All labeled AC's have their quotas exactly met while vacancies exist in some unlabeled categories. No man who is not already assigned to an unlabeled category is eligible for one. So now the quotas in these unlabeled AC's must be adjusted.

b. The group of unlabeled AC's becomes the original set to be subjected to the shredding process as described above. FQF first adjusts the quotas on these categories so that the total quota for the unlabeled AC's is equal to the number of men currently assigned to those AC's. Then TRANSFER moves a maximum number of men from categories with an excess to categories with a shortage. The labels which TRANSFER sets become the means for partitioning the set of AC's. If all quotas are exactly met, then the processing terminates. Otherwise some AC's are labeled and the rest unlabeled. The labeled AC's are all overfilled or exactly filled, and the unlabeled are all exactly filled or underfilled. No man from a labeled AC is eligible for an unlabeled one. The shredding process continues with FQF setting the quotas and TRANSFER moving men and doing the partitioning. The quota adjustment is such that no adjusted quota ever exceeds the original quota. Also the order of processing is such that the unlabeled sets of AC's are completely shredded before the labeled sets.

c. Everything that has been discussed so far applies only to schools with equal priorities. The word "priority" implies a process in which every effort is made to fill a high priority AC quota before a lower priority category is even considered. There is no attempt to share or distribute shortages over categories of unequal priority. The quota for high priority AC's must be filled to the fullest extent possible before a single man enters a category of lower priority. Sharing is an entirely different concept. If there are enough men to fill all AC's to 75% of their quotas, 'fair-sharing" would fill each to 75% of its quota if possible. "Unfair-sharing" might fill an important AC to 90% of its quota and a less important one to only 60%, but it still attempts to distribute shortages according to some pattern rather than try to fill the important categories 100% and the least important categories 0%.

d. The program is written so that both the priority system and the sharing system can be used in conjunction with one another. At each stage, MAXFLOW and TRANSFER work with all the AC's whose priorities exceed a certain threshold. At first only the highest priority AC's are run. Then the threshold is lowered and the highest priority and second-highest priority categories are run with MAXFLOW or TRANSFER, and so forth. However, at the second stage, MAXFLOW starts with the assignments previously made to the highest priority categories. A characteristic of the algorithm is that a man is never transferred out of an AC unless a replacement is found for him. Thus, the number of men assigned to the highest priority AC's never diminishes.

e. After each call of MAXFLOW or TRANSFER, quota reduction and sharing is executed only on the AC's whose priorities exactly equal the current value of the threshold. AC's of higher or lower priority than the threshold are ignored. Thus sharing is done only among categories of equal priority.

3. FQF

a. The method of solution underlying the sharing system requires that differential values be associated with different degrees of shortage. It is assumed that the greater the shortage, the more vital each man becomes. The closer the reduced quota is to the original quota, the less important each additional man is to the successful operation of his organization. These assumptions can be expressed by the equation:

$$\frac{dv_j}{dr_j} = k_j \frac{q_j - r_j}{r_j}$$

where: q_j = the original quota in category j

r_j = the reduced quota which is the number of men who will finally be assigned to category j

v_j = the value associated with attaining a reduced quota of r_j

k_j = a constant of proportionality called the "share-coefficient" for category j.

b. The equation states that the rate of change of value with change in reduced quota is directly proportional to the deficit and inversely proportional to the reduced quota.

c. The quota-reduction and sharing problem is to find a set of reduced quotas (r_j) which maximize the total value,

$$V = \sum_{j=1}^{JOBS} v_j$$

subject to the constraints that

(1) $$\sum_{j=1}^{JOBS} r_j = N = \text{the total number of assigned men}$$

(2) $r_j \geq o$ for all j

(3) $r_j \leq q_j$ for all j.

d. The problem can be solved with the method of Lagrange multipliers as follows:

$$\text{Let } V^* = \sum_{j=1}^{JOBS} v_j - \lambda \left\{ \left(\sum_{j=1}^{JOBS} r_j \right) - N \right\}$$

The solution is that set of (r_j) and λ for which

$$\frac{\partial V^*}{\partial r_j} = 0 \quad \text{and} \quad \frac{\partial V^*}{\partial \lambda} = 0. \quad \text{Thus}$$

$$\frac{\partial V^*}{\partial r_j} = \frac{\partial v_j}{\partial r_j} - \lambda = k_j \frac{q_j - r_j}{r_j} - \lambda = 0 \quad \text{(see footnote)}$$

Notice that this condition of optimality assures that for non-negative k_j, $r_j > 0$ for all j. This fact makes it possible to apply the Lagrange multiplier technique. In the more general case of non-negative variables ($r_j \geq 0$), all possible permutations of J-1 variables would have to be set equal to zero in order to evaluate the boundaries of the non-negative orthant. As a practical matter, it is necessary to arrive at a set of integer r_j's because reduced quotas may not be fractional for the assignment problem. A partial rounded sum procedure is used to round the r_j's so as to insure that the sum of the integer r_j's equal N.

$$\text{and} \quad \frac{V^*}{\partial \lambda} = \sum_{j=1}^{JOBS} r_j - N = 0.$$

$$\text{The equation} \quad k_j \frac{q_j - r_j}{r_j} = \lambda$$

tells us that the solution of the quota-sharing problem occurs when the rate of change of value with respect to the reduced quota is the same for all AC's. Furthermore, the equivalent equation

$$k_j = \lambda \frac{r_j}{q_j - r_j}$$

tells how to compute the share coefficients from a given or recommended pattern of reduced quotas. Then all the share coefficients can be multiplied by an arbitrary constant, λ , without changing the solution.

e. For a given set of share-coefficients, however, the constant of multiplication, λ , is unknown and must be computed. First, it should be noted that the reduced quotas are given by the formula

$$r_j = q_j \frac{k_j}{\lambda + k_j}$$

Note that the right hand side of the formula contains the unknown multiplier λ. To solve for λ, an equation must be constructed which contains λ as the only unknown. Such as equation can be obtained by summing the r_j in the preceding formula.

$$\sum_{j=1}^{JOBS} q_j \frac{k_j}{\lambda + k_j} = N, \text{ since } \sum_{j=1}^{JOBS} r_j = N.$$

f. Unfortunately, there is no explicit solution of this equation for λ. Some iterative scheme such as Newton-Raphson iteration must be employed (3)

$$\text{Let} \quad f(\lambda) = \sum_{j=1}^{JOBS} q_j \frac{k_j}{\lambda + k_j} - N.$$

Let λ_n be the value of the n^{th} approximation to λ. Then a closer approximation to λ can be obtained by:

$$\lambda_{n+1} = \lambda_n + \Delta\lambda_n$$

where $$\Delta\lambda_n = \frac{-f(\lambda_n)}{f'(\lambda_n)}$$

Now $$f'(\lambda_n) = \frac{df(\lambda_n)}{d\lambda_n} = -\sum_{j=1}^{JOBS} q_j \frac{k_j}{(\lambda_n + k_j)^2}$$

(See Footnote.)

hence $$\lambda_{n+1} = \lambda_n + \frac{\sum_{j=1}^{JOBS} q_j \frac{k_j}{\lambda_n + k_j} - N}{\sum_{j=1}^{JOBS} q_j \frac{k_j}{(\lambda_n + k_j)^2}}$$

g. Of course, any iterative scheme requires an initial approximation, λ_o. To develop such an approximation, consider what happens if the reduced quotas are all large.

Then $$\frac{\lambda_L}{JOBS} \sum_{j=1}^{JOBS} \frac{1}{k_j} = \frac{1}{JOBS} \sum_{j=1}^{JOBS} \frac{q_j - r_j}{r_j} \sim \frac{Q - N}{N}.$$

In other words, the mean ratio of deficit to reduced quota is approximately equal to the ratio of the total deficit to the total reduced quota.

Hence $$\lambda_L \sim \frac{Q - N}{N} \cdot \frac{JOBS}{\sum_{j=1}^{JOBS} \frac{1}{k_j}}$$

Notice that all relevant k_j are positive, so that $f'(\lambda_n) \neq 0$.

h. On the other hand, if the reduced quotas are small,

$$\frac{1}{\lambda_S} \cdot \frac{1}{JOBS} \sum_{j=1}^{JOBS} k_j = \frac{1}{JOBS} \sum_{j=1}^{JOBS} \frac{r_j}{q_j - r_j} \sim \frac{N}{Q - N}$$

$$\text{So} \quad \lambda_S = \frac{Q - N}{N} \cdot \frac{\sum_{j=1}^{JOBS} k_j}{JOBS}$$

i. It is sensible to use a weighted average of λ_L and λ_S for the initial value of λ_o. The weights should depend on the size of the reduced quota. The simplest combination would be

$$\lambda_o = \frac{N}{Q} \lambda_L + \frac{Q - N}{Q} \lambda_S$$

and this is the formula which is employed in the program. Experience indicates that this initial estimate of λ_o is close enough to the root to assure convergence.

j. A few further observations should be made about the sharing formula. First, it should be noted that a given set of share-coefficients implies a certain set of percentages of reduced quotas to original quotas. AC's with the same share-coefficients will have the same percentages of reduced quota to original quota, if sufficient men are available to fill the reduced quotas. For example, if 55 men are available for fair-sharing among two AC's with quotas 10 and 100, then the reduced quotas will be 5 and 50, even though the absolute amount of shortage is ten times as large in the second AC as it is in the first. Secondly, it should be noted that the sharing formulas prevent the reduced quotas from falling below zero or exceeding the original quotas as long as $0 \leq k_j \leq \infty$. More precisely, $r_j \longrightarrow 0$ as $k_j \longrightarrow 0$ and $r_j \longrightarrow q_j$ as $k_j \longrightarrow \infty$. Although the sharing formulas may appear complex, they are actually the simplest ones which have these properties.

APPENDIX E

FEASFIND ALGORITHM

1. General

a. Each assignment category will accept men on any one of up to 32 qualification levels. The levels are ordered in terms of decreasing desirability, with the lowest called the mandatory level. At the time that FEASFIND is entered, quotas have been set for each category based exclusively on the mandatory levels, and an assignment has been produced in which these quotas are met. FEASFIND attempts to partition the quotas for each category into quotas for each of its qualification levels, so that an assignment can still be made and so that the quotas are pushed as far as possible toward the top qualification levels. The FEASFIND procedure consists of multiple calls to MAXFLOW (see Appendix C).

b. Initially all quotas for qualification levels other than the mandatory are zero, and the mandatory quotas are all met. The men who are currently assigned into the mandatory level in category one are placed in the unassigned pool for reconsideration by MAXFLOW. The quota for the highest qualification level for this category is set equal to the quota for the mandatory level, and the quota for the mandatory level is set to zero. MAXFLOW is called to attempt to fill the newly established quota for the highest qualification level. MAXFLOW (it will be recalled) may cross assignment categories in an attempt to find qualified men. However, MAXFLOW has the property that a man will not be moved out of an assignment category unless there is a man to replace him. Hence, categories which were full before the call to MAXFLOW remain full afterwards. The net effect of this assignment is to decrease the number of unassigned men by an amount equal to the number of men assigned into the highest priority level of category one. The quota on that level is then set equal to the number of men assigned into it and the mandatory quota to the number of men left unassigned. These men are then reassigned into the mandatory level, and thus the integrity of the overall quota for this category is maintained.

c. The top level of the next assignment category is next processed, then the top level of the next assignment category, etc. Thus eventually the final frozen quotas are established for the most desirable level of each category. The procedure is repeated for each succeeding level of desirability. The processing of a category terminates when all levels for that category have been treated or when there are no more men in the mandatory level for that category. In the latter case, the mandatory level is removed from the system.

d. Because the categories must appear as a list within the computer and because FEASFIND processing results in an unintentional bias for categories appearing earlier in the list, the order in which the categories are processed is reversed for successive levels. The bias occurs because MAXFLOW assigns a man with multiple eligibilities to the first quota for which he is qualified and the alternation of processing is an attempt to compensate for this bias.

e. The alternation process mentioned in d above is modified if any level in any assignment category fails to receive any assignments. In this instance all references to the null level are deleted and on the next level iteration those categories which failed to receive personnel on the Nth level are considered first on the N+1 level. The net effect of this modification is to give first consideration on any level to those assignment categories which have gone the greatest number of iterations without receiving desirable types of personnel.

f. FEASFIND priorities are processed in the same manner as QUOTFIND priorities with all levels of priority one assignment categories being considered before all priority two levels, all priority two levels before priority three, etc.

APPENDIX F

OPTIMIZE ALGORITHM

1. Algorithm

a. The OPTIMIZE Algorithm assigns men to categories in such a way that a linear payoff function is maximized. Each assignment category has specific qualification restrictions and quota requirements, and each man may be qualified for several of these categories. The solution is such that a man is qualified for the category to which he is assigned and the quotas on the categories are not exceeded.

Let I = number of men

J = number of categories

Q_j = quota for category j

P_{ij} = payoff if man i is assigned to category j. $P_{ij} > 0$ except if man i is unqualified for category j, in which case $P_{ij} = -\infty$.

We desire to assign each man to one category in such a way that

(1) $$\sum_{i=1}^{I} \sum_{j=1}^{J} P_{ij} \; x_{ij} \quad \text{is maximized, where}$$

$$x_{ij} = \begin{cases} 1 \text{ if man } i \text{ is assigned to category } j \\ 0 \text{ otherwise.} \end{cases}$$

b. The problem can be fully solved only if there is a feasible assignment, i.e. there is some assignment possible in which every man is assigned and all quotas are met. If the feasibility condition does not hold, then an assignment will result in which some quotas are not filled and/or some men are left unassigned. In this case the maximality of the payoff function cannot be assured.

c. OPTIMIZE is divided into two main sections, DUAL and MAXFLOW. (The description of MAXFLOW appears in AppendixC and should be read prior to this discussion.) The assignment procedure consists of an alternation of processing between these sections. DUAL specifies for which categories each man is eligible. MAXFLOW then assigns a maximum number of men under these eligibility restrictions without exceeding quotas. Then DUAL changes the eligibilities of certain men, without destroying the eligibility of any man for the category to which he is presently assigned, and once more gives control to MAXFLOW. The procedure eventually terminates in DUAL. It is determined at that time whether the optimal assignment has been found or whether no feasible solution exists.

d. In order to determine eligibilities, DUAL employs a set of so called "dual" variables $(U_i \;\; V_j)$ $(i = 1, \ldots I; j = 1, \ldots, J)$ (1). The dual variables are unrestricted in sign. Throughout our discussion we employ the convention that any computation which involves $\pm\infty$ yields $-\infty$ as a result.

Define

(2) $$r_{ij} = P_{ij} - U_i - V_j$$

The values assumed by U_i and V_j will always be such that $r_{ij} \leq 0$. Then eligibility is defined as follows: man i is eligible for category j if $r_{ij} = 0$. Thus, if man i_o is eligible for category j_o

(3) $$U_{i_o} = P_{i_o j_o} - V_{j_o} \geq P_{i_o j} - V_j \quad \text{for any } j.$$

Notice that a man can never be eligible for a category for which he is not qualified, because $r_{ij} = -\infty$. After each pass through MAXFLOW, the dual variables are adjusted, but the adjustments are always made such that $r'_{ij} = r_{ij} = 0$ if man i is assigned to category j.

e. We can now see why an assignment under the above definition of eligibility maximizes the payoff function if the feasibility constraints are met. Suppose (x_{ij}) is assignment array determined by an application of OPTIMIZE, and suppose (x'_{ij}) is any other assignment array. For a fixed i there is exactly one j_o such that $x_{ij_o} = 1$. For all other j, $x_{ij} = 0$.

Thus $$\sum_j (P_{ij} - V_j)\, x_{ij} = P_{ij_o} - V_{j_o}.$$

By the eligibility requirements (3) we have $$P_{ij_o} - V_{j_o} \geq P_{ij} - V_j \text{ for all } j.$$

Therefore $$\sum_j (P_{ij} - V_j)\, x_{ij} \geq \sum_j (P_{ij} - V_j)\, x'_{ij}.$$

Then $$\sum_i \sum_j (P_{ij} - V_j)\, x_{ij} \geq \sum_i \sum_j (P_{ij} - V_j)\, x'_{ij}$$

$$\sum_i \sum_j P_{ij}\, x_{ij} - \sum_j (V_j \sum_i x_{ij}) \geq \sum_i \sum_j P_{ij}\, x'_{ij} - \sum_j (V_j \sum_i x'_{ij})$$

$$\sum_i \sum_j P_{ij}\, x_{ij} - \sum_j V_j\, Q_j \geq \sum_i \sum_j P_{ij}\, x'_{ij} - \sum_j V_j\, Q_j$$

$$\sum_i \sum_j P_{ij}\, x_{ij} \geq \sum_i \sum_j P_{ij}\, x'_{ij}$$

Thus (x_{ij}) maximizes the payoff function.

f. The procedure may begin with any finite values for the V_j. Then set

$$U_i = \max_j (P_{ij} - V_j)$$

This has the effect of making $r_{ij} \leq 0$ and making man i eligible for at least one category, unless he is unqualified for every category, in which case the problem is *a priori* infeasible. Then the V_j are adjusted as follows:

$$V'_j = \max_i (p_{ij} - U_i)$$

This makes at least one man eligible for category j, unless there is no man qualified for this category. If man i_o was eligible for category j_o under V_{j_o} then $V'_{j_o} = V_{j_o}$, and he remains eligible under V'_{j_o}. This is so because

$$P_{i_o j_o} - U_{i_o} - V_{j_o} = 0 \text{ implies } V_{j_o} = P_{i_o j_o} - U_{i_o}$$

$$\text{and } P_{ij_o} - U_i - V_{j_o} \leq 0 \text{ implies } V_{j_o} \geq P_{ij_o} - U_i$$

$$\text{thus } V'_{j_o} = \max (P_{ij_o} - U_i) = P_{i_o j_o} - U_{i_o} = V_{j_o}.$$

Once the initial U_i, V_j are determined, the first pass through MAXFLOW is made.

g. It is easy to see that if a feasible solution exists and the V_j are chosen properly, then the desired assignment will be achieved by the first application of MAXFLOW. It is probably possible to devise a method for initially estimating the values of V_j so as to reduce the number of passes through MAXFLOW. In the absence of such a V_j estimator we initially set $V_j = 0$.

h. We now turn to a discussion of the adjustment of the dual variables by DUAL. After a pass through MAXFLOW some men have been assigned to categories, the labeling procedure is complete, and no categories with vacancies have been labeled. By altering the U_i and V_j we can accomplish the following:

A. Every man remains eligible for the category to which he is presently assigned

B. Every label which currently exists remains valid

C. At least one labeled man becomes eligible for an unlabeled category

D. $r'_{ij} \leq 0$

To achieve this, let

$$\bar{r} = \max (r_{ij}), \text{ where}$$

i runs over all labeled men and j runs over all unlabeled categories.

i. If $\bar{r} = -\infty$ or is undefined then the procedure terminates. This may happen in the following ways:

(1) There are no labeled men and all quotas are met. In this case we have a feasible assignment which therefore maximizes the payoff function.

(2) There are no labeled men, but some quotas are not met. Thus, all men have been assigned, but there may be some way to reassign them so as to increase the payoff.

(3) There are no unlabeled categories. Thus, all quotas are met but men remain unassigned. It may be possible to improve the payoff by switching men who are assigned for those who are unassigned, although the payoff cannot be improved by switching assigned men only.

(4) $\bar{r} = -\infty$. Thus no labeled man is eligible for any unlabeled category. In this case there are unassigned men and unfilled categories, but the qualifications of the men are such that there is no way to move them about so as to achieve a greater number assigned, it may be possible to alter the assignments so as to increase the payoff.

j. In the non-terminal situation $\bar{r}$ is defined and finite. $\bar{r} < 0$, because if $r_{i_o j_o} = 0$ where man i_o is labeled then man i_o is eligible for category j_o and hence category j_o is labeled. Change the U_i and V_j as follows:

$$U_i' = \begin{cases} U_i + \bar{r} & \text{if man } i \text{ is labeled} \\ U_i & \text{if man } i \text{ is unlabeled} \end{cases}$$

$$V_j' = \begin{cases} V_j - \bar{r} & \text{if category } j \text{ is labeled} \\ V_j & \text{if category } j \text{ is unlabeled} \end{cases}$$

We show that this adjustment satisfies conditions A, B, C, and D above.

A. If man i is presently assigned to category j, then either man i and category j are both labeled or both unlabeled. In either case

$$r_{ij}' = P_{ij} - U_i' - V_j' = P_{ij} - U_i - V_j = r_{ij} = 0,$$

so that man i remains eligible for category j.

B. A man is labeled if he is either unassigned or assigned to a labeled category. A category is labeled if there is a labeled man eligible for it. If $r_{ij} = 0$, where man i is labeled, then category j is labeled and thus $r_{ij}' = 0$. This, along with condition A, implies that all labels remain valid.

C. For labeled man i and unlabeled category j we have

$$r_{ij}' = P_{ij} - U_i' - V_j' = P_{ij} - (U_i + \bar{r}) - V_j = r_{ij} - \bar{r}$$

Thus by definition of $\bar{r}$ there exists a labeled man i_o and an unlabeled category j_o such that $r_{i_o j_o}' = 0$, i.e. a labeled man becomes eligible for an unlabeled category.

D. Break this down into three cases:

(1) Man i and category j are both labeled or both unlabeled. Then $r'_{ij} = r_{ij} \leq 0$.

(2) Man i is labeled and category j is unlabeled. Then

$$r'_{ij} - P_{ij} - (U_j + \bar{r}) - V_j = r_{ij} - \bar{r} \leq 0 \text{ by definition of } \bar{r}.$$

(3) Man i is unlabeled and category j is labeled. Then

$$r'_{ij} = P_{ij} - U_j - (V_j - \bar{r}) = r_{ij} + r < 0$$

since

$$r_{ij} \leq 0 \text{ and } \bar{r} < 0.$$

Because of conditions A and B we may return to MAXFLOW and continue the labeling process where we left off. By condition C at least one more category will be labeled. It is this condition which assures us of eventual termination.

APPENDIX G

USER INFORMATION AND OPERATING INSTRUCTIONS

1. SYSTEM COMPONENTS

COBRA is a large single-submission system composed of a number of programs and models combined through the use of overlays. An overall system monitor integrates the operation of the following components:

a. PREDICT

PREDICT minimizes the key-punching and verification effort required to supply the COBRA system with information concerning assignment categories for a particular run. PREDICT enables the user to store on tape a "Dictionary" file of all possible assignment categories. The data includes all prerequisites, both mandatory and desired, associated with every USMC assignment category, the FEASFIND priority, and the selection relevant Area Aptitude Composite associated with the assignment category.

For a given run, the user prepares Quota Control Card. These cards carry only the assignment category identification symbol, the QUOTFIND priority and share coefficient, and the quota. COBRA subsequently integrates quota data from the Quota Control Cards and prerequisite specifications from PREDICT.

Convenient procedures are provided whereby items may be added to the Dictionary and item specifications may be changed through use of input cards.

b. QUOTFIND

The QUOTFIND algorithm deals with the problem of determining feasible quotas, i.e., it reduces and adjusts quotas systematically whenever the quality or quantity of recruits available present an infeasible solution to the assignment problem.[1] The algorithm is concerned only with "fill" — subsequent solutions are concerned with "fit."

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[1] The essential parameters of this solution are:

(a) the original quotas,
(b) the number of recruits available for assignment,
(c) the importance (priorities and sharing coefficients) associated with each assignment category,
(d) the mandatory prerequisites associated with each assignment category, and
(e) the assignment eligibilities of available recruits (the "talent mix").

QUOTFIND permits specification of absolute quota fill priorities for assignment categories, forcing COBRA, if possible, to fill higher priority quotas regardless of the consequences to lower priority quotas. If a shortage of qualified recruits occurs for categories with equivalent priorities, the QUOTFIND algorithm accommodates shortage sharing policies for applying user specified sharing coefficients. QUOTFIND will maximize the fill of all quotas in accordance with priorities and sharing coefficients, and all categories will have assigned to them recruits whose qualifications satisfy or exceed the mandatory prerequisites associated with the quota.

The QUOTFIND algorithm never increases a quota, and will reduce the quota only when, under the policies and shortages, it cannot be filled by available talent. Within the same absolute priority level, quota reductions when necessary are distributed equally among assignment categories of equal importance and unequally among those of unequal importance. This algorithm is essential to COBRA as it provides a feasible basis for subsequent model optimizations.

c. FEASFIND

The FEASFIND algorithm is designed to improve the quality of recruit assignments. QUOTFIND arrives at quota fills while considering only mandatory prerequisites. FEASFIND, on the other hand, attempts to improve the quality of assignments by maximizing the number of "desirably" qualified recruits assigned to each quota. Desirably qualified recruits are defined as those meeting user-specified desirable prerequisites[2] — prerequisites which are desirable but not mandatory for assignment to the category.

The system objectives of FEASFIND are:

- preserve quotas determined by QUOTFIND, without exception; and
- assign recruits meeting desirable prerequisites to the maximum extent possible, in accordance with user-specified desirable prerequisite levels for each assignment category.

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2 A desirable prerequisite level must include all characteristics or properties which are mandatory for assignment to the job category plus one or more additional characteristics which potentially reduce the number of recruits eligible for the category. Desirable assignment prerequisites are expressed in hierarchical levels. For Electronics School, for example, a 3-year term of enlistment is mandatory. It is desirable, however, to select men with a 4-year term of enlistment.

Once recruits have been tentatively assigned by QUOTFIND, they may be exchanged or "swapped" among the categories for which they meet at least mandatory prerequisites so long as the swap does not change the "fill" of quotas. FEASFIND searches for recruit exchanges which improve the solution "fit." The search follows a user-specified sequence (FEASFIND priority), identifying, if necessary, long chains of exchanges in which as many as one hundred exchanges will be made to improve one recruit's assignment. FEASFIND searches for exchanges satisfying a certain desirable prerequisite "level" until the search is exhausted; the model then utilizes a relaxation strategy in which the next most desirable level of prerequisites is substituted, and the search for beneficial exchanges continues at that level. This search-relaxation-search process is repeated until it has exhausted all possible exchanges for all assignment categories, and the categories are filled with recruits who possess desired prerequisites to the maximum extent possible.

d. OPTIMIZE

The solutions obtained by the QUOTFIND and FEASFIND models:

— insure the maximum fill of all quotas,

— insure adherence to at least mandatory prerequisites for all assignment categories, and

— insure maximum accommodation of desirable assignment prerequisites.

While COBRA has arrived at the maximum number of assignments meeting desirable prerequisites, the best possible arrangement of assignments, from the standpoint of selection-relevant scores, has yet to be achieved.

The OPTIMIZE model maximizes performance estimates relating each recruit to every possible assignment category for which he is eligible. These estimates are derived from the recruit's aptitude test battery. In short, the OPTIMIZE program maximizes the probability of success of each recruit in his ultimate assignment. While preserving the quotas derived by the QUOTFIND solution as well as the desirable prerequisite set of constraints attained by the FEASFIND solution, OPTIMIZE endeavors to improve the arrangement of assignments even further by exchanges which assign recruits to assignment categories for which they possess their highest aptitude composite.

2. IMPORTANT DEFINITIONS AND CONCEPTS

a. Super-Quotas

At various points in the solution, the COBRA system attempts to reduce the size of the man-job matrix by identifying and grouping assignment categories (columns) which have identical solution relevant characteristics, e.g., selection prerequisites. By this reduction, several assignment categories may be represented by a single column, the quota of which is the sum of the original assignment category quotas. The word "super-quota" has been coined to identify such a column or group of assignment categories.

Once grouped into a "super-quota, the aggregate quota is used in the assignment process. Following optimization, the recruits selected for the super-quota are distributed (on a random basis) to quotas in the ratios that each separate quota bears to the super-quota.

b. Assignment-Relevant Properties

When discussing a recruit's assignment-relevant properties, the word "property" has a special and limited meaning. It implies a variable that is strictly bi-valued. Properties are in reality true or false responses to statements about the characteristics of a recruit. Such statements as: "The recruit has a GT score equal to or greater than 100" and "The recruit's age is 18 or older" define assignment-relevant properties since these statements can be categorized as true or false. The assignment system allows the user to define up to 82 such properties for use as assignment criteria. Note that a property, as defined, may refer to more than a single recruit characteristic and the full set of logical operators "OR," "AND," "GREATER THAN," "LESS THAN," "EQUAL TO," and "NOT" may be used to formulate a particular property. Hence, the yes-no response to the statement "The recruit has a GT score less than 120 or an ETST score less than 60" defines a single legitimate property.

c. Assignment-Relevant Prerequisites

When recruit properties are tested by an assignment category to select specific types of personnel, they become assignment "prerequisites." Specifically, an individual prerequisite may be a property (true value), "NOT" a property (false value), or an "ANDED" combination of several properties, an "ANDED" combination of "NOT" properties, or an "ANDED" combination of properties and "NOT" properties. The individual properties and/or "NOT" properties are then "ANDED" together to form a prerequisite set. By comparing the prerequisite set associated with an assignment category with the properties possessed by a recruit, the assignment system can rapidly determine the eligibility of the recruit for a particular assignment category. It is important to note that individual prerequisites are "ANDED" together in the prerequisite set. It is not possible to "OR" them together. Thus, a prerequisite set can restrict assignment to trainees with property "A" and property "B," but cannot restrict assignment to trainees with property "A" or property "B."

d. Bydates

Two types of reporting dates are available to the user:

— a "not before" date, and

— a "not later than" date.

These dates are referred to as the "Early Bydate" and the "Late Bydate" respectively. Provision to honor these bydates was incorporated into the COBRA system so that: a) class convening dates or reporting dates for specified quotas could be met, and b) pooling times at assignment locations could be minimized.

e. Prerequisite Levels

Each prerequisite set is called a "level." The COBRA system permits the user to define up to thirty-two different prerequisite sets or levels for each assignment category. Each level defines the type of trainee desired. Levels are ordered for each assignment category from a level specifying the most desirable type of recruit (level one) down to a "least desirable" level which specifies a type of recruit who meets only the minimum assignment prerequisites for the assignment category. During the FEASFIND process, the system will maximize the assignment of recruits of the type specified in level one. If the quota for a particular assignment category cannot be met at this level, because of a talent or personnel shortage, the system maximizes the fill of the remaining quota with level two types of personnel, then level three types, etc. The process of moving from the most desirable level to less desirable levels is referred to as a "relaxation of levels." The "least desirable" level in each category is referred to as the mandatory level since it specifies the mandatory prerequisites for entry into the assignment category.

f. Priorities

At various points in COBRA, numeric priorities are used to control the order in which assignment categories are considered. The priorities specified for each assignment category need not be unique, i.e., several assignment categories may have the same priority. When this occurs, assignment categories of equal priority are given equal consideration.

3. HARDWARE REQUIREMENTS AND CAPACITIES

a. Equipment

COBRA is run on a two-bank (65,536 — 48 bit word memory) Control Data Corporation 3600 computer, with 12 tape drives, under the CDC standard TAPE SCOPE monitor and FORTRAN overlay systems.

b. Capacities

Up to 7500 recruits, excluding Special and Category II assignments, can be assigned with the COBRA system.

No more than 32 prerequisite levels may be specified for a single assignment symbol. No more than 78 properties may be "ANDED" together to define a single prerequisite level. No more than 18 different bydates may be used in a given assignment run. No more than 2000 quotas may be specified on any run; the quotas must combine into 500 or fewer super-quotas. The system will abort if more than 500 super-quotas are generated for QUOTFIND processing.

FEASFIND cannot generate more than 500 levels including the mandatory levels. When FEASFIND has utilized all 500 levels available, maximization is terminated, and OPTIMIZE is called as though level maximization had been completed. This constraint affects only the quality of the FEASFIND solution and will not produce fatal system diagnostics. All assignments will meet mandatory prerequisites.

No more than 1000 Special Assignments may be specified on any run.

c. Typical vs. Maximum Utilization

The following chart summarizes the system capacities described above, together with typical values found in system operation for a single recruit depot.

Characteristic	Typical value+	System capacity
Trainee Inputs	2,500	7,500
Quota categories submitted	110	2,000
Super-quotas generated	65	500
Total levels generated (super-quotas plus relaxations)	90	500
Defined prerequisite levels per assignment category	1-7	32
Dictionary capacity (super-quotas)	160	3,000
Solution time (in minutes)	5-60	Not applicable

+Typical value is for a single recruit depot.

4. SYSTEM APPLICATIONS

COBRA is a single submission, multiple overlay system. The elimination of human intervention has obvious advantages for the user. COBRA also possesses sufficient flexibility to permit two alternative submission configurations. As Exhibit #1 indicates, the user may terminate a run following PREDICT operations. This submission configuration permits the user to revise the Dictionary, or to obtain a Dictionary listing. This is a relatively infrequent COBRA application.

An alternative application in which processing is terminated following QUOTFIND is typically employed prior to the making of a complete assignment run. This application is strongly recommended, as unsatisfactory results are made available prior to executing the entire run. Review of these results will permit the user to judge the extent to which the solution may be over-constrained or the input card error rate is excessive. Once the user is satisfied with the inputs, a normal system execution may be completed.

5. SYSTEM OPERATIONS (see Exhibit #1)

To initiate operations, the LOADMAIN card calls MAIN, which in turn calls the CONTROL program. The CONTROL program checks all system control cards (see Exhibit #2) and determines the programs to be used in the particular application. Programs needed for system operations are called when required.

The COBRA system passes recruit data through a PREPROCESSOR. Recruit service numbers are checked for duplication, a table of available Category II MOS's is established, and a table of recruit graduation dates with associated extended bydates is established. In general, two extended bydates of different lengths are used. Formal School (Categories I and III) assignments require a 50-day bydate; General Duty (Category IV) assignments require a 60-day bydate. These bydates allow a trainee to complete ITR and recruit leave before reporting for his assignment. The number of days to extend an outpost date for any particular assignment category can be varied by a control card.

COBRA also checks the Quota Control Cards, extracting from each the assignment symbol, quota, priority information, and bydates. After storing this information, COBRA searches the dictionary tape to extract the corresponding course prerequisite information for each of these assignment symbols. If an assignment symbol appearing on a Quota Control Card does not appear on the COBRA Dictionary Tape, fatal diagnostics occur and the run must be resubmitted with correct information. All bydates specified by Quota Control Cards are converted to the closest appropriate outpost dates. If an Early Bydate cannot be accommodated by the latest available outpost date, the bydate will be moved to agree with the last available outpost date. If a Late Bydate is equal to or is later than the latest available outpost date, it is eliminated because all trainees are eligible. A maximum of 14 outpost dates can be used for bydates. The same date may be used as an Early Bydate and/or Late Bydate.[3]

While processing the Quota Control Cards, COBRA checks also for the use of Multiplier Cards. If a Multiplier Card is detected, all quotas on succeeding Quota Control Cards are modified by the multiplier specified by the Multiplier Card. This process continues until: a) another Multiplier Card is detected, or b) all Quota Control Cards have been processed.

After the COBRA system has extracted Quota Control Cards and Dictionary tape information, as described above, the DATA PROCESSOR is called to verify the information received on each trainee and make the Special and Category II assignments. In some cases, erroneous and missing data on a trainee can be repaired; in other instances, erroneous or missing data on a trainee may prohibit his assignment. Such individuals are subsequently assigned by the Recruit Depots. Individuals not assigned to Special and Category II quotas are assigned by the three optimal allocation algorithms: QUOTFIND, FEASFIND, and OPTIMIZE.

[3] Note that more than fourteen different bydates may be specified in the Quota Control Cards, but no more than fourteen remain after the outpost-date conversion.

After the assignment outcome is determined, all assignments are posted to the assignments tape to be sorted and a report summarizing the selection relevant score means, standard deviations, and level distributions is made. An additional report is produced to summarize assignments by DOD occupational groups and by assignees' mental ability groups. Once the assignments and reports have been made, the individuals are sorted by name within recruit training platoon by assignment.

6. INPUTS

a. Dictionary Tape

COBRA maintains a Dictionary of all possible assignment categories. Each assignment category is identified by an assignment symbol, i.e., a seven-character name. For each assignment symbol, an entry on the Dictionary Tape specifies the selection-relevant area aptitude score, the FEASFIND priority, and all "levels" of assignment prerequisites for the category (see example, Exhibit #6).

The Dictionary Tape may be listed or edited through COBRA. The user may add or delete assignment categories and/or modify the parameters and levels associated with existing categories.

b. Quota Control Cards

For each assignment category to be filled, the user prepares a Quota Control Card (see Exhibit #13) which provides the assignment symbol, bydate, quota, fill priority, and shortage sharing parameter (share coefficient).

c. Trainee Data

Data on each trainee to be assigned is supplied to COBRA via magnetic tape by the Datatape Generator program. This data, obtained from Raw Data Cards on recruits (forwarded by the Recruit Depots; see Exhibit #7), includes the recruit's area aptitude scores, physical characteristics, expected date of graduation from recruit training, and other selection-relevant characteristics.

7. SYSTEM OPERATING PROCEDURES

A typical assignment run on the CDC 3600 computer requires inputs as follows:

— a Master Control Deck and sort deck;
— a DATATAPE, compiled from Raw Data Cards provided by the Recruit Depots;
— Quota Control Cards, prepared from data contained in the Recruit Distribution Letter (DFB1/1-pcm; MCO 1500.12c);

— the system Dictionary Tape, containing a complete catalog of schools and their entrance requirements; and

— the COBRA overlay tape, containing the main system programs.

a. Master Control Deck

A master control deck containing specific operating instructions to the computer and to the main COBRA program must be assembled. It is by means of this deck that the program is loaded into the computer and executed. The control deck may also be employed to select certain features of the system without executing a complete run. (Exhibit #14 presents a generalized control deck description; Exhibit #15 shows the CDC Process Request form used to submit a run.)

b. DATATAPE

Recruit input data is provided by the DATATAPE, which is compiled from raw data cards supplied by the Recruit Depots. The compilation procedure is as follows:

(1) Raw data cards must be transferred to tape for initial sorting. (See Exhibits #7, 8, 9.)

(2) Information on the raw data tape must be sorted into service number sequence, using the Control Data Sort II library routine. A separate sort control deck must be prepared for each Recruit Depot due to format differences in raw data inputs.

(3) Compilation is accomplished with the DATATAPE generation program, the sorted raw data tape, and associated control cards. (See Exhibits #10, 11, and 12.)

c. Quota Control Cards

The recruit distribution letter (DFB1/1-pcm; Ref. MCO 1500.12c) provides all information needed for punching Control Cards for use in the main control deck during COBRA assignment runs. (Exhibit #13 illustrates card formats for Standard Quotas, Category II, and Special Assignments.)

d. Dictionary Tape

(1) Compilation

The Dictionary Tape contains a complete catalog of all schools and their entrance requirements. In addition to the mandatory prerequisites for entrance, the desirable prerequisites (by level) are also provided. The Dictionary Tape is compiled from School Header Cards (Exhibit #3) and Restriction Cards (Exhibit #4) submitted in the following sequence:

SCHOOL HEADER CARD, SCHOOL 1

Restriction Card Restriction Card Restriction Card etc.	(Level 1 — each card may contain as many as nine properties or characteristics for a maximum of 82 specified per level. As many cards as needed may be used.)
Restriction Card Restriction Card etc.	(Level 2 — this level is less restrictive than Level 1; each subsequent level is less restrictive than the one(s) preceding it.)
Restriction Card Restriction Card etc.	(Separately for all levels following 1 and 2 above)
Restriction Card Restriction Card etc.	(Mandatory Level — this level contains the minimal requirements for admission to the school; it is always the last level for each school.)

SCHOOL HEADER CARD, SCHOOL 2

(Followed by the same kind of Restriction Card sequences, as shown for School 1 above, which are applicable for levels.)

Dictionary Tape compilation also requires input of the main system overlay tape and a compilation control deck. This control deck immediately precedes the Header Cards and Restriction Cards. (See Exhibit #5.)

(2) Modifications of Dictionary

Routinely, changes are made to the Dictionary Tape to reflect changes in policy and training prerequisites and/or deletion or addition of new assignment categories. Such changes can be accomplished quickly and easily through COBRA control cards. (See Exhibits #2(b) and #5.)

Occasionally, new properties may be required. If fewer than 82 properties have already been defined, the addition is not difficult. If 82 properties have been defined, however, then at least one property must be deleted for each new property to be added. The deletion of a property may require extensive revision or new preparation of the Dictionary Tape and, consequently, may require more time to implement than the addition of a property. In either instance, modification of the defined properties requires program changes in COBRA. The user, therefore, should request property modifications well in advance of any Dictionary Tape modifications involving the new property definitions.

8. OUTPUTS

a. Dictionary Report

This report is produced only when specifically requested or when the Dictionary Tape has been modified during the run. It provides a listing, carefully indexed, of each assignment category, with the assignment prerequisites associated with each relaxation level clearly identified. In addition, the report provides:

- symbols of other assignment categories, if any, that have been combined into the same super-quota;
- FEASFIND priority;
- selection relevant area aptitude score; and
- the total number of relaxation levels presently available to the solution.

(Exhibit #6 presents an excerpt from the report.)

b. Preprocessor Reports

Three reports are provided by the Preprocessor: a) the names, service numbers, and recruit training platoon numbers of all duplicated service numbers; b) a list of the Category II MOS's available for assignment and the number of trainees having the MOS; and c) a table of available outpost dates, the associated projected reporting dates, and the number of trainees outposting on each date.

c. Subquota Control Card Listing

This report lists the quota cards, as punched. (See Exhibit #16.)

d. Data Processor Reports

Reports provided by the Data Processor include: a) a list of errors detected, if any, in trainee data and a list of six-month reservists, if any, rejected; b) a Category II assignment summary; and c) a Special Assignment summary.

e. Quota Distribution Report

This report presents the quota allocation outcome obtained by QUOTFIND. Original quotas, feasible reduced quotas, and the percentage of fill arrived at by the solution are listed for each assignment category. Absolute priorities and share coefficients are also presented. (See Exhibit #17.)

f. Feasibility Distribution Report

This report contains a detailed breakdown of: a) the number of trainees assigned to each relaxation level within an assignment category, and b) an assessment of the quality of assignment results at each level and for the assignment category, as measured by the selection relevant area aptitude score average and variability (means and standard deviations). It should be noted that the system reports these results by super-quota where assignment categories have been combined. (See Exhibit #18.)

g. Final Distribution Report by Assignment Symbol

Final results for each assignment category as defined by the quota control cards are provided by this report. The number of trainees assigned as well as their selection-relevant area aptitude score average and variability are presented. Page and super-quota numbers, shown with the assignment symbols, cross-reference entries in this table with the Feasibility Distribution Report described above. (See Exhibit #19.)

h. Summary Information Report

This report presents overall summary information showing the solution on each pass. It indicates the total number of men assigned, total mean payoff, total number of relaxations, and total number of levels required by the solution. The total mean payoff is the average selection relevant area aptitude score for all men assigned by the solution. (See Exhibit #20.)

i. DOD Occupational Group Assignment Summary

This report contains a detailed breakdown of: a) DOD occupational groups, b) the MOS's assigned to each DOD occupational group, and c) the number of mental groups ., III, IVA, and IVB, and college graduate personnel assigned to each MOS. (See Exhibit #21.)

j. Individual Assignment Listing

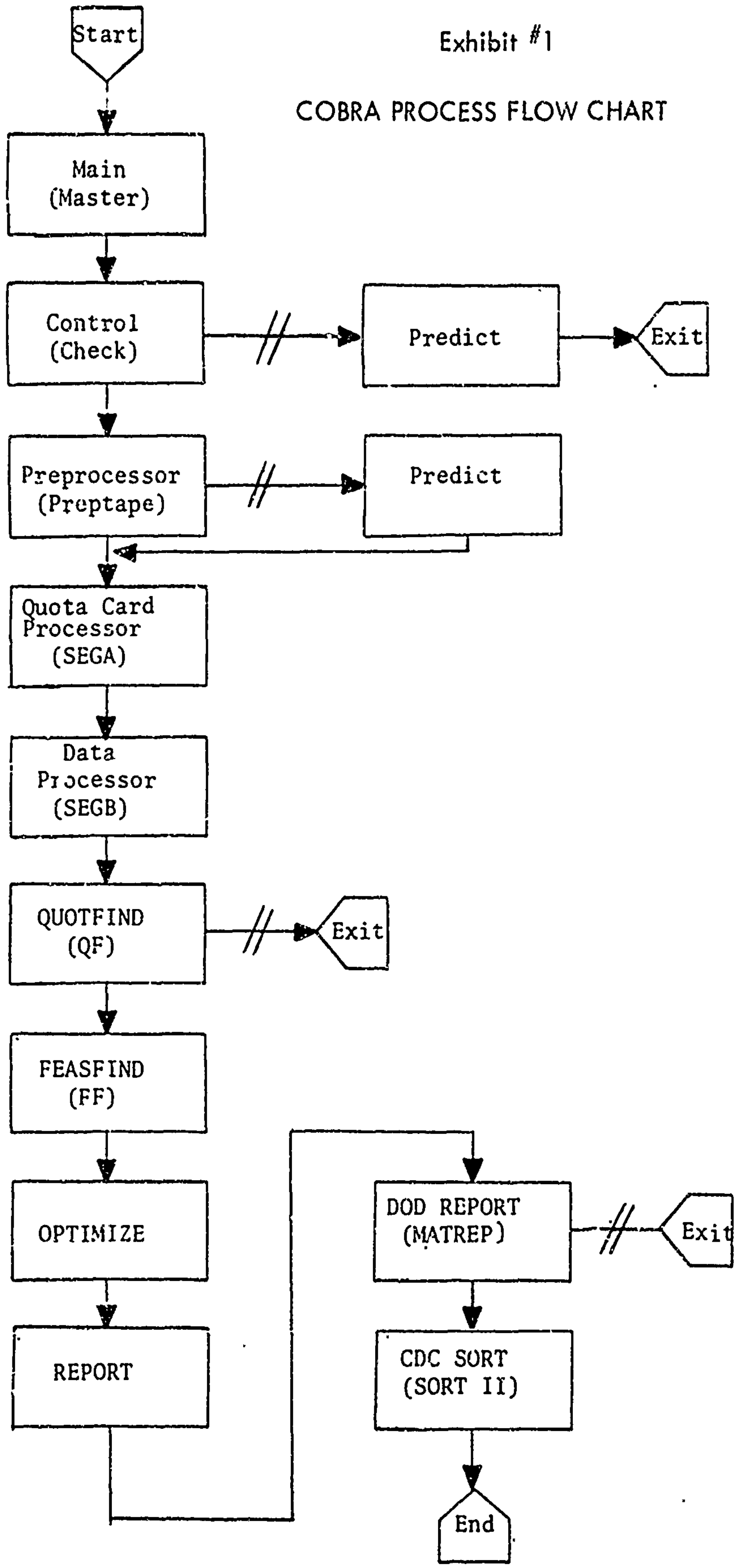
This report lists the sorted individual assignments. (See Exhibit #22.)

k. Assignment Cards

A complete set of the sorted individual assignment cards is output for use by the Recruit Depots. (See Exhibit #23 for card formats.)

Exhibit #1

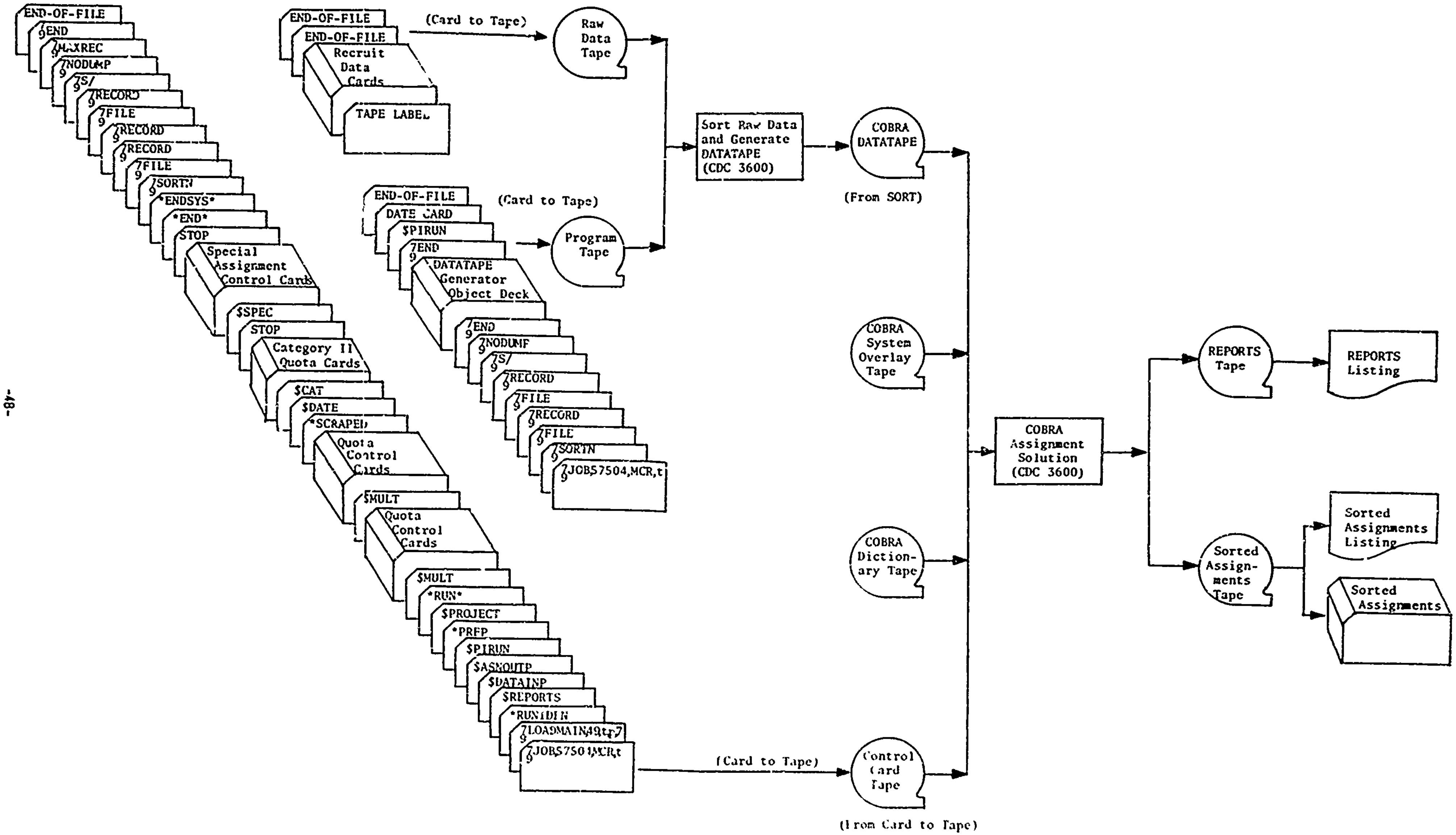
COBRA PROCESS FLOW CHART



**Program names are given in parentheses if not identical with process as noted.

Exhibit #2 (a)

COBRA INPUT-OUTPUT FLOW CHART



COBRA Dictionary Input-Output Flow Chart

(PREDICT Up-date)

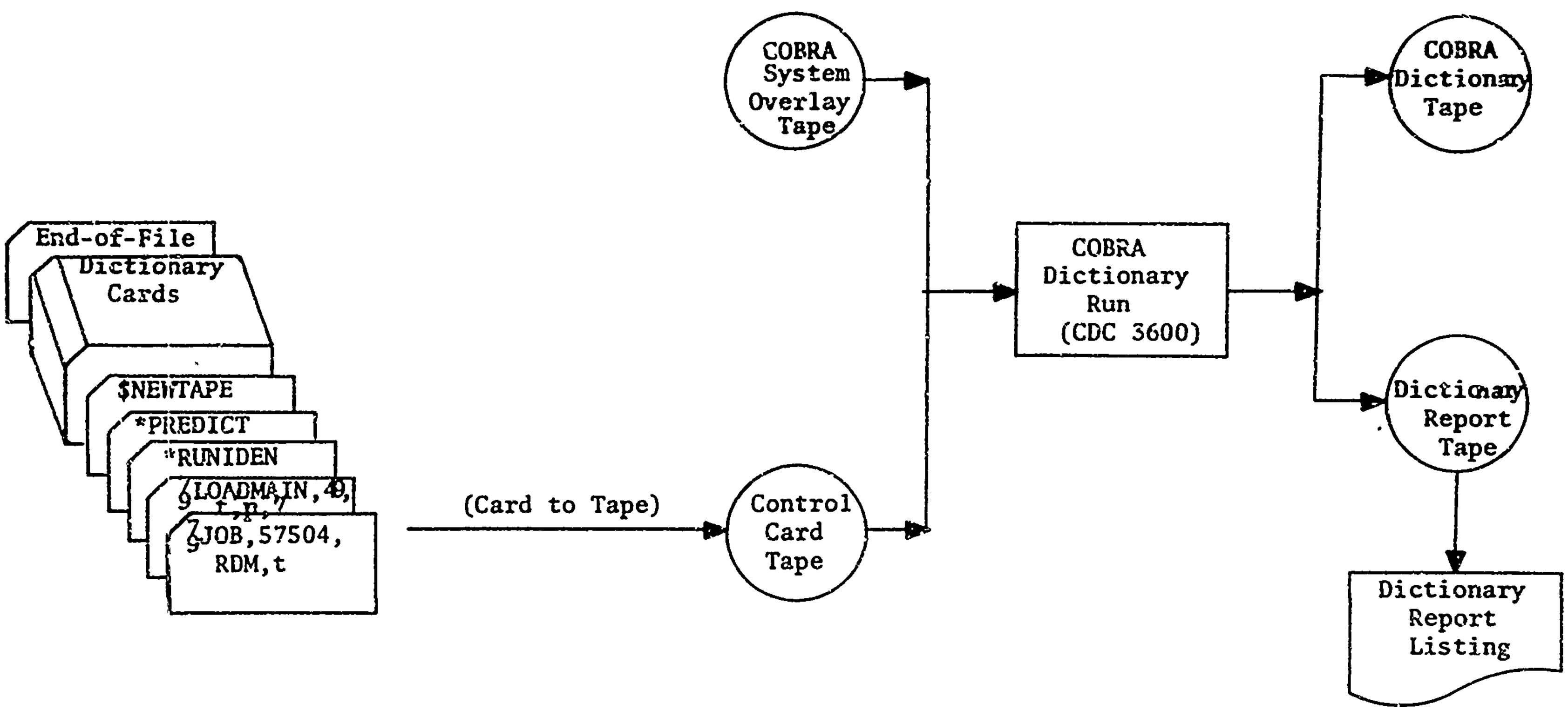


Exhibit #3

SCHOOL HEADER CARD FORMAT

Card Columns	Description	Remarks
1	$	Control punch
2-8	Assignment symbol	
16	FEASFIND priority	
47-48	Selection-relevant area aptitude score to be maximized for this job category.	IN, AE, etc.

Exhibit #4

RESTRICTION LEVEL CARD FORMAT

Card Columns	Description	Remarks
1	Level number	If more than one card is used for a level, the same number will be punched in column 1 for each. Levels need not be numbered sequentially, but they must appear in ascending order. For example, cards numbered 1-3-6-8 are acceptable, but cards numbered 1-3-2-4 are not in ascending order and would be considered mis-filed.
2-8	Property name	1st property field on the card*
9-16	Property name	2nd property field on the card
17-24	Property name	3rd property field on the card
25-32	Property name	4th property field on the card
33-40	Property name	5th property field on the card
41-48	Property name	6th property field on the card
49-56	Property name	7th property field on the card
57-64	Property name	8th property field on the card
65-72	Property name	9th property field on the card.

*Free field, blank fields permissible.

Exhibit #5

DICTIONARY COMPILATION CONTROL DECK LAYOUT

Card column description		Explanation
$^{7}_{9}$ JOB,57504,MCC,300		
$^{7}_{9}$ LOADMAIN,49,300,999999,7		
*RUNIDEN	USMC DICTIONARY	"USMC DICTIONARY" begins in column 17
*PREDICT		Control cards calling compilation routine from overlay tape
$NEWTAPE		

SCHOOL HEADER CARDS AND RESTRICTION LEVEL CARDS

FOLLOW HERE IN PROPER SEQUENCE

Exhibit #6

DICTIONARY OF ASSIGNMENT PREREQUISITES BY JOB CATAGORY USMC DICTIONARY

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SUPER QUOTA NO.74

ASSIGN. SYMBOL REC

PRIORITY	BASE CODE	BASE NAME	OCC FIELD	AA SCORE	NO.LEVEL
1				GT	6

LEVEL	RESTRICTIONS				
DESIRE.	NONAVG	GT120+	ETST60+	CITIZEN	AR100+
	HSGRAD	ALGEBRA	4YR		
RELAX. 1	NONAVG	GT110+	ETST60+	CITIZEN	AR100+
	HSGRAD	ALGEBRA	4YR		
RELAX. 2	NONAVG	3OR4YR	GT110+	ETST60+	CITIZEN
	AR100+	HSGRAD	ALGEBRA		
RELAX. 3	NONAVG	3OR4YR	GT110+	ETST60+	CITIZEN
	AR100+	ALGEBRA			
RELAX. 4	NONAVG	3OR4YR	GT110+	ETST60+	CITIZEN
MANDAT.	NONAVG	3OR4YR	GT100+	ETST60+	CITIZEN

Exhibit #6 (continued)

DICTIONARY OF ASSIGNMENT PREREQUISITES BY JOB CATAGORY USMC DICTIONARY 09/19/68 PAGE 143

ASSIGN.	SUBQUOT.	PAGE NO.
S2531	22	38
S2532A	21	37
S2532	20	36
S3531AA	19	35
S3531AB	18	34
S3531A	17	33
S3531MA	16	32
S3531MB	15	31
S3531	14	30
SEADU	13	29
SHOERPR	12	28
SHOFCOP	11	27
SOMALI	4	20
SPANISH	4	20
SPARTY	9	25
SPHOTO	10	26
SWAHILI	4	20
TANKS	9	25
TELEOPR	8	24
THAILAN	4	20
TIGINYA	4	20
TOPSURV	7	23
TTOC	6	22
TTRPR	5	21
VIETLAN	4	20
VORAD	3	19
WELDER	2	18
YEOMAN	1	17

Exhibit #7

RECRUIT RAW DATA CARD FORMATS

SAN DIEGO

Card columns	Description
1-11	Name
12-13	Initials
14-20	Service number
21	Component
22	Obligation
23	School subject (algebra or trigonometry)
24-25	Age
26	Education
27-30	Platoon number
31-32	Outpost date (day)
33-56	Area aptitude scores: IN 33-35, AE 36-38, EL 39-41, GM 42-44, MM 45-47, CL 48-50, GT 51-53, and RC 54-56
57-58	Typing
59-60	ETST
61	VE 100+
62	AR 100+
63	PA 105+
64	Citizenship
65	Mental group
66	1st high AA
67-70	Avia. and Cat. II MOS
71	Height
72	EDPT
73	Visual acuity
74	Color perception
75	Flight crew/Jump volunteer
76	ALAT
77-80	---blank---

PARRIS ISLAND

Card columns	Description
1-12	Name
13-14	Initials
15	School subject (algebra or trigonometry)
16	VE 100+
17	AR 100+
18	Component
19	Obligation
20-26	Service number
27-28	ETST
29-30	Typing
31	Height
32-34	---not used---
35	Education
36-39	Outpost date (Day 36-37, Mo. 38-39)
40-41	Age
42	PA 105+
43	Citizenship
44	Mental group
45	ALAT
46	EDPT
47	Visual acuity
48	Color perception
49	Flight crew/Jump volunteer
50-53	Avia. and Cat. II MOS
54-77	Area aptitude scores: IN 54-56, AE 57-59, EL 60-62, GM 63-65, MM 66-68, CL 69-71, GT 72-74, and RC 75-77
78-80	Platoon number

Exhibit #8

TAPE LABEL CARD FORMAT

Card columns	Description	Remarks
1-8	5()bb000	b = blank
9-13	PIRUN (or SDRUN)	
23-24	01	

Exhibit #9

CARD-TO-TAPE DECK SET-UP

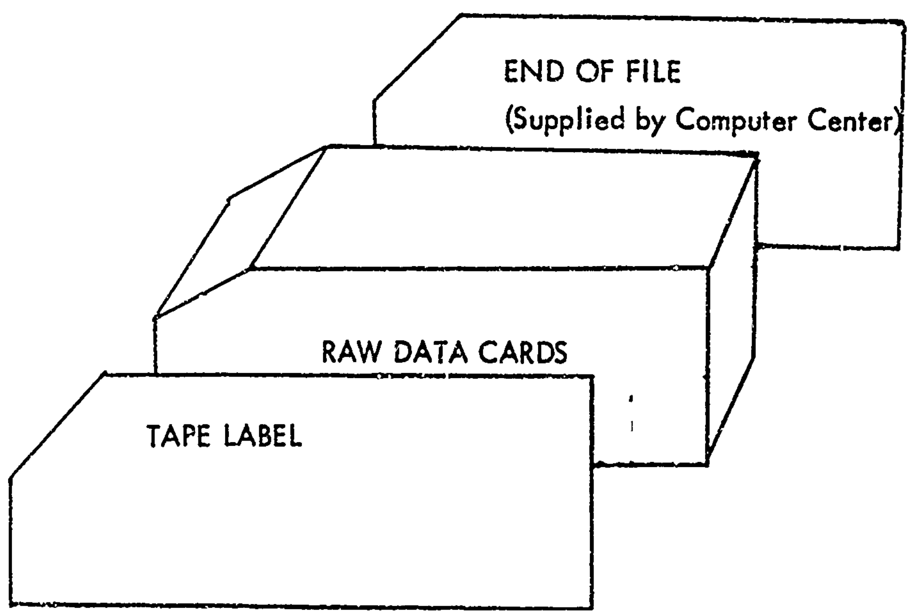

Exhibit #10

DEPOT IDENTIFIER CARD FORMAT

Card columns	Description	Remarks
1-6	$PIRUN	Parris Island Identifier Card
1-6	*SDRUN	San Diego Identifier Card

Exhibit #11

OUTPOST DATE/DATATAPE DESCRIPTION CARD FORMAT

Card columns	Description	Remarks
1-2	01	
4-5	Month of outposting	01, 02, 03, etc.
7-8	DATATAPE LUN	Automatically 05 if left blank; 01—19 permitted.
10-12	*Blocking Factor	1-100 allowed; automatically 100 if left blank.

*Blocked data is transferred into core more rapidly than unblocked, making it desirable to use the blocked input.

Exhibit #12

DATATAPE PROGRAM DECK SET-UP

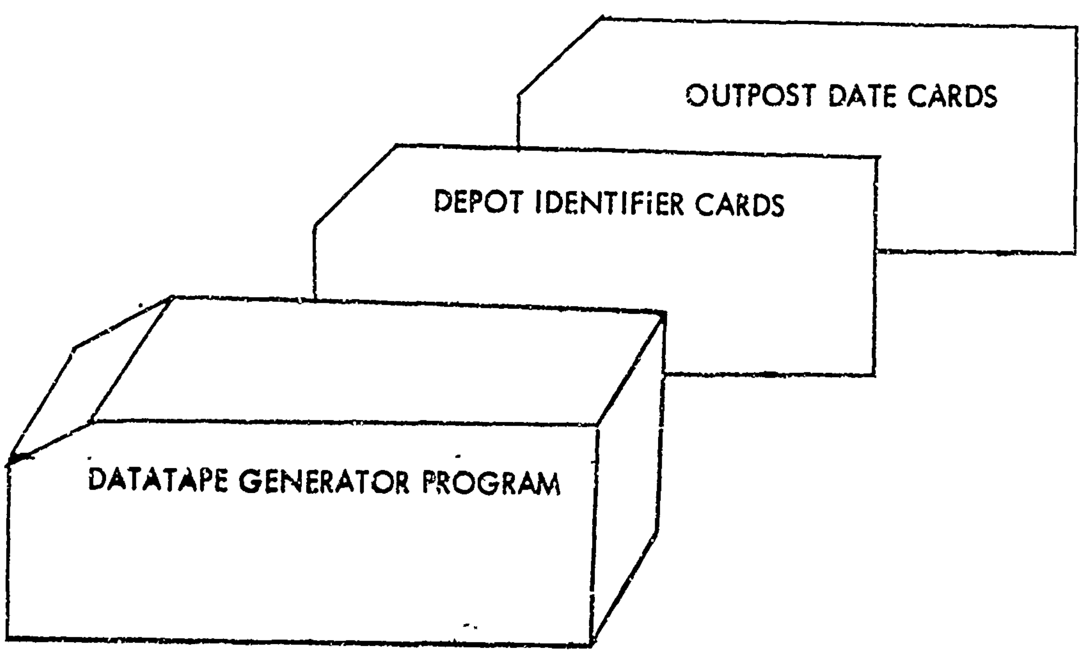

Exhibit #13

CONTROL CARD FORMATS

Type of card	Card columns	Description	Remarks
STANDARD QUOTA CONTROL CARD	1- 7	Assignment symbol	From Dictionary; left justified
	9-13	Quota	Right-justified
	15-18	Priority	Right-justified
	20-25	Share Coefficient	Decimal number .00001 to 99999. (Free-field)
	27-32	Early by-date (YYMMDD)	
	34-39	Late by-date (YYMMDD)	Blank if more than 60 days from outpost time
	41-59	QUOTA SERIAL NUMBER	Literal name.
	61-66	Quota serial number	Actual number punched here
CATEGORY II CONTROL CARD	1- 4	MOS	
	6- 8	Quota	Right-justified
	10-15	Quota serial number	Actual number punched here
SPECIAL ASSIGNMENT CONTROL CARD	6-12	Service number	
	14-17	MOS to be assigned	
	19-24	Quota serial number	Actual number punched here
QUOTA MULTIPLIER CARD	1-5	$MULT	Literal name
	9-16	Multiplier	A per cent punched as a decimal number, with the decimal point.

Exhibit #14

MASTER CONTROL DECK SET-UP

Card column description (Beginning in column 1)	Explanation (Optional or special purpose cards in parentheses.)
$^{7}_{9}$JOB,57504,RDM,300	Computer Control Card; $^{7}_{9}$JOB = card identification; 57504 = USMC account number; RDM = USMC account initials; 300 = maximum estimated run time in minutes.
$^{7}_{9}$LOADMAIN,49,300,999999,7	Computer Control Card; $^{7}_{9}$LOADMAIN = card identification; 49 = advises computer that main program is contained on tape number 49 (overlay tape); 300 = maximum run time in minutes; 999999 = maximum number of lines of printed output on standard output; 7 = code number which will instruct computer to print out entire contents of core storage in the event of a malfunctioning run.
*RUNIDEN SAN DIEGO (or PARRIS ISLAND)	System control card. This card identifies the type of run, whether SAN DIEGO or PARRIS ISLAND. The location name starts in card column 17.
$REPORTS 02	(Optional card. Normally, reports will be printed on the standard output tape, Logical Unit Number 61 — LUN 61. LUN 61 actually refers to a computer tape, labeled 61. Use of a $REPORTS card enables the user to specify a label number other than 61. Numbers which may be used are 01-19, if not used elsewhere, and are punched in columns 17 and 18.)
$DATAINP 03	(Optional card. Specifies new LUN for Data Input Tape. This card may be deleted if the data input tape is LUN 05. Numbers available are 01-19, punched in columns 17 and 18.)
$ASNOUTP 04	(Optional card. Specifies new LUN for assignment tape in card columns 17 and 18. May be deleted if output LUN is 01. If this card is used, the SORT DECK must be altered to agree with it. For this reason, under normal conditions this card should not be used.)
$SDRUN (or $PIRUN)	This card specifies the origin of the trainee input data: San Diego or Parris Island.
PREP	Sets up call to By-date Processor.
$PROJECT	Changes length of projection times from outpost dates to reporting dates. (Formal school date is in card columns 10 and 11; General duty assignment in columns 13 and 14.)

Exhibit #14
Master Control Deck Set-Up — Continued.

Card column description	Explanation (Optional/special purpose cards in parentheses)
*QFINDER	(Optional card. Sets up call to QUOTFIND routine. Used in cases where results of QUOTFIND only are desired.)
RUN	Sets up calls to QUOTFIND, FEASFIND and OPTIMIZE. This card is used for complete assignment runs and should not be included if a *QFINDER card is present.
$MULT 1.5	Quota Multiplier Card. This card precedes Quota Control Cards whose quotas must be modified by a constant multiple. Value of multiple is punched, with decimal point, into columns 9-16.

QUOTA CONTROL CARDS ARE INSERTED HERE.

$MULT 1.05	Quota Multiplier Card

ADDITIONAL QUOTA CONTROL CARDS INSERTED HERE.

*SCRAPED	Sets up call to Data Processor.
$DATE 67	Date card, containing year of graduation from Boot Camp of trainee inputs (columns 9 and 10).
$CAT	Sets up call to process Category II assignments, if any.

CATEGORY II ASSIGNMENT CARDS ARE FILED HERE.

STOP	This card indicates that all Category II assignment cards have been read in. NOTE: SCAT, CAT II Assignment Cards and STOP card are treated as a single set of control cards. They must all be present for a CAT II assignment run to be successful; none may be present for the program to otherwise properly function.
$SPEC	Sets up call to process special assignments, if any.

SPECIAL ASSIGNMENT CARDS ARE FILED HERE.

STOP	Control card indicating that all special assignment cards have been read. NOTE: $SPEC, Special Assignment Cards and STOP card are treated as a single set of control cards. They must all be present for a Special Assignment run to be successful; none may be present for the program to otherwise properly function.

Exhibit #14
Master Control Deck Set-Up — Continued.

Card column description	Explanation
END	Signals end of pre-process control card deck.
ENDSYS	Signals end of system operation.

SORT DECK INSERTED HERE. ASSIGNMENTS ARE SORTED ACCORDING TO ASSIGNMENT NUMBER, SO THAT EACH ASSIGNMENT HEADER CARD IS FOLLOWED BY THE APPROPRIATE RECRUIT DATA CARDS ACCORDING TO PLATOON NUMBER, AND IN ALPHABETICAL ORDER WITHIN PLATOONS. THERE IS A SPECIAL SORT DECK FOR EACH RECRUIT DEPOT DUE TO FORMAT DIFFERENCES.

Exhibit #15(a) DATATAPE Generation Submission

PROCESS REQUEST

CONTROL DATA CORPORATION – WASHINGTON DATA CENTER

USMC	5 7 5 0 4 R D M			
CUSTOMER NAME	CONTROL # INIT.	SEQUENCE #	INIT.	LOG #

REG. ☐ ASAP ☐ PR. ☐ WORK IN:

INITIATOR (SIGNATURE) TEL # EXT DATE SUBMITTED SERVICE DESIRED

MAIN SYSTEM

3600 X KP/KV ☐
3200 TAB ☐
160-A ☐
SPECIFY

TYPE of RUN

SCOPE X OSAS ☐
SORT X ☐
T/P ☐
SPECIFY

TIME (in Min.)	EST.	MAX.
160-A (only)		
3600/3200	3	6
List	1	2
Plot		

WORK DUE OUT:

WISH TO ATTEND ☐

TIME RECORD

DATE TIME ON / TIME OFF MACH #

DATE TIME ON / TIME OFF MACH #

DATE TIME ON / TIME OFF MACH #

DATE TIME ON / TIME OFF MACH #

DATE TIME ON / TIME OFF MACH #

DATE TIME ON / TIME OFF MACH #

INSTRUCTIONS

PREPROCESSING

ID. or DESCR.	KP	KV	OTHER
Card-to-tape Data, to			LUN 02

SINGLE STEP OPERATIONS

C/T ☐ C/C ☐
T/C ☐ C/PR ☐
T/PR ☐ ☐

INPUT

I.D.	P.T.	BIN	BCD	LABEL	DEN	REEL	GOES TO
Cards	(Program)						60

DENS.	KEY
200 BPI	2
556 BPI	5
800 BPI	8

MAIN PROCESSOR

3600 / 3200 / 160-A

Chan Phys U.						
Logical Unit	02	01	05			
TYPE ⊙	IR	S	R			
REEL #						
DENSITY	5	5	5			

SLJ	SLS
1	1
2	2
4	4

Circle if ON at START

3600

PHYS. UNIT						
Logical Unit	31	32	33	34	35	36
TYPE ⊙	S	S	S	S	S	S
REEL #						
DENSITY	5	5	5	5	5	5

SS (3600)
SLJ (3200)
NONE
1 4
2 5
3 6
Circle if ON at START

OUTPUT

FROM	ID REEL	LIST	PU	PLOT	BIN	BCD	Files	Copies	Space
61		✓				✓	1		P.C.

⊙ TYPE	KEY
From File	F
From File with Ring	FØ
Scratch	S
To be Reserved	R
From 160-A	I
Customer Tape	C

POST PROCESSING

I.D. or DESCRIPTION	DECOLL.	INTERPR.	DELIVER

See attached sheet for additional instructions. ☐

OPERATOR'S COMMENT

RAN O.K. ☐ ERROR ☐ OVERRUN ☐

See console image on back ☐

Additional progr. instructions:

WORK OUT

Requests for adjustments of any charge recorded on this Process Request must be submitted within 72 hours of completion of processing.

Exhibit #15(b) Dictionary Up-date Submission

PROCESS REQUEST

CONTROL DATA CORPORATION – WASHINGTON DATA CENTER

CUSTOMER NAME	CONTROL #	INIT.	SEQUENCE #	INIT.	LOG #
USMC	5 7 5 0 4	R D M			

INITIATOR (SIGNATURE) — TEL # EXT. — DATE SUBMITTED — SERVICE DESIRED: REG. ☐ ASAP ☐ PR. ☐ — WORK IN:

MAIN SYSTEM

3600 (X) KP/KV ☐
3200 ☐ TAB ☐
160-A ☐ ______ ☐ SPECIFY

TYPE of RUN

SCOPE (X) OSAS ☐
SORT ☐ ______ ☐
T/P ☐ ______ ☐ SPECIFY

TIME (in Min.)	EST.	MAX.
160-A (only)		
3600/3200	2	4
List	10	15
Plot		

WORK DUE OUT.

WISH TO ATTEND ☐

TIME RECORD

DATE	TIME ON / TIME OFF	MACH #			

OPERATOR'S COMMENT

RAN O.K. ☐ ERROR ☐ OVERRUN ☐

See console image on back ☐

Additional progr. instructions:

Do Not Batch

If a LUN 20 is asked for, wait until LUN 30 has rewound and is ready, then type "LOOK".

INSTRUCTIONS

PREPROCESSING

ID. or DESCR.	KP	KV	OTHER

SINGLE STEP OPERATIONS

C/T ☐ C/C ☐
T/C ☐ C/PR ☐
T/PR ☐ ______ ☐

INPUT

I.D.	P.T.	BIN	BCD	LABEL	DEN	REEL	GOES TO
Cards							60

DENS.	KEY
200 BPI	2
556 BPI	5
800 BPI	8

MAIN PROCESSOR

3600 / 3200 / 160-A

Chan/Phys U.						
Logical Unit		49	20	61	30	
TYPE ⊙		F	R	R	S	
REEL #		5133				
DENSITY		5	5	5	5	

SLJ: 1 2 4 — SLS: 1 2 4 — Circle if ON at START

3600

PHYS. UNIT						
Logical Unit						
TYPE ⊙						
REEL #						
DENSITY						

SS (3600) SLJ (3200)
NONE
1 4
2 5
3 6
Circle if ON at START

OUTPUT

FROM	ID/REEL	LIST	PU	PLOT	BIN	BCD	Files	Copies	Space
61		✓				✓	1		P.C.

⊙TYPE	KEY
From File	F
From File with Ring	FØ
Scratch	S
To be Reserved	R
From 160-A	I
Customer Tape	C

POST PROCESSING

I.D. or DESCRIPTION	DECOLL.	INTERPR.	DELIVER

See attached sheet for additional instructions. ☐

Requests for adjustments of any charge recorded on this Process Request must be submitted within 72 hours of completion of processing.

WORK OUT

Exhibit #15(c) QUOTFIND Submission

PROCESS REQUEST

CONTROL DATA CORPORATION – WASHINGTON DATA CENTER

CUSTOMER NAME	CONTROL #	INIT.	SEQUENCE #	INIT.	LOG #
USMC	5 7 5 0 4	R D M			WORK IN:

INITIATOR (SIGNATURE) — TEL # EXT — DATE SUBMITTED — SERVICE DESIRED: REG. ☐ ASAP ☐ PR. ☐

MAIN SYSTEM

3600 ☒ KP/KV ☐
3200 ☐ TAB ☐
160-A ☐ ______ ☐ SPECIFY

TYPE of RUN

SCOPE ☒ OSAS ☐
SORT ☐ ______ ☐
T/P ☐ ______ ☐ SPECIFY

TIME (in Min.)	EST.	MAX.
160-A (only)		
3600/3200	8	15
List	3	5
Plot		

WORK DUE OUT:

WISH TO ATTEND ☐

TIME RECORD

DATE	TIME ON / TIME OFF	MACH #			
DATE	TIME ON / TIME OFF	MACH #			
DATE	TIME ON / TIME OFF	MACH #			
DATE	TIME ON / TIME OFF	MACH #			
DATE	TIME ON / TIME OFF	MACH #			
DATE	TIME ON / TIME OFF	MACH #			

OPERATOR'S COMMENT

RAN O.K. ☐ ERROR ☐ OVERRUN ☐

See console image on back ☐

Additional progr. instructions:

INSTRUCTIONS

PREPROCESSING

ID. or DESCR.	KP	KV	OTHER

SINGLE STEP OPERATIONS

C/T ☐ C/C ☐
T/C ☐ C/PR ☐
T/PR ☐ ______ ☐

INPUT

I.D.	P.T.	BIN	BCD	LABEL	DEN	REEL	GOES TO
Cards							60

DENS.	KEY
200 BPI	2
556 BPI	5
800 BPI	8

MAIN PROCESSOR

3600 / 3200 / 160-A

Chan/Phys U.							
Logical Unit		49	20				
TYPE ⊙		F	F				
REEL #		5133	2354				
DENSITY							

SLJ	SLS
1	1
2	2
4	4

Circle if ON at START

3600

PHYS. UNIT							
Logical Unit		Many Scratch					
TYPE ⊙							
REEL #							
DENSITY							

SS (3600)
SLJ (3200)
NONE
1 4
2 5
3 6
Circle if ON at START

OUTPUT

FROM	ID/REEL	LIST	PU	PLOT	BIN	BCD	Files	Copies	Space
61		✓				✓	1		P.C.

⊙TYPE	KEY
From File	F
From File with Ring	FØ
Scratch	S
To be Reserved	R
From 160-A	I
Customer Tape	C

POST PROCESSING

I.D. or DESCRIPTION	DECOLL.	INTERPR.	DELIVER

See attached sheet for additional instructions. ☐

WORK OUT

Requests for adjustments of any charge recorded on this Process Request must be made within 72 hours of completion of processing.

Exhibit #15(d) COBRA System Submission

PROCESS REQUEST

CONTROL DATA CORPORATION - WASHINGTON DATA CENTER

CUSTOMER NAME	CONTROL #	INIT.	SEQUENCE #	INIT.	LOG #
USMC	5 7 5 0 4	R D M			

REG. ☐ ASAP ☐ PR. ☐ — WORK IN:

INITIATOR (SIGNATURE) — TEL # EXT — DATE SUBMITTED — SERVICE DESIRED

MAIN SYSTEM

3600 ☒ KP/KV ☐
3200 ☐ TAB ☐
160-A ☐ ______ ☐ SPECIFY

TYPE of RUN

SCOPE X OSAS
SORT X
T/P ☐
SPECIFY

TIME (in Min.)	EST.	MAX.
160-A (only)		
3600, 3200	40	60
List	8	15
Plot		

WORK DUE OUT:

WISH TO ATTEND ☐

TIME RECORD

DATE	TIME ON / TIME OFF	MACH #			

INSTRUCTIONS

PREPROCESSING

I.D. or DESCR.	KP	KV	OTHER

SINGLE STEP OPERATIONS

C/T ☐ C/C ☐
T/C ☐ C/PR ☐
T/PR ☐ ______ ☐

INPUT

I.D.	P.T.	BIN	BCD	LABEL	DEN	REEL	GOES TO
CARDS							60

DENS.	KEY
200 BPI	2
556 BPI	5
800 BPI	8

MAIN PROCESSOR

3600 3200 160-A

Chan Phys U.						
Logical Unit	49	20	05	61	03	
TYPE	F	F	F	R	R	
REEL #	5133	2354	2229			
DENSITY	5	5	5	5	5	

SLJ: 1, 2, 4 — SLS: 1, 2, 4 — Circle if ON at START

3600

PHYS. UNIT						
Logical Unit	M A N Y	S C R A T C H				
TYPE ⊙						
REEL #						
DENSITY						

SS (3600) SLJ (3200) NONE 1 4 2 5 3 6 Circle if ON at START

OUTPUT

FROM	ID REEL	LIST	PU	PLOT	BIN	BCD	Files	Copies	Space
61		✓				✓	1		PC
03		✓				✓	1		SS
03			✓			✓	1		

⊙TYPE	KEY
From File	F
From File with Ring	FØ
Scratch	S
To be Reserved	R
From 160-A	I
Customer Tape	C

POST PROCESSING

I.D. or DESCRIPTION	DECOLL.	INTERPR.	DELIVER

See attached sheet for additional instructions. ☐

OPERATOR'S COMMENT

RAN O.K. ☐ ERROR ☐ OVERRUN ☐

See console image on back ☐

Additional progr. instructions:

DO NOT BATCH

Same Tape }

WORK OUT

Requests for adjustments of any charge recorded on this Process Request must be submitted within 72 hours of completion of processing.

Exhibit #16

CANNEB	001	4	1.0	681202	QUOTA SERIAL NUMBER 825635
BDC	013	4	1.0	681127	QUOTA SERIAL NUMBER 825636
AUTOMT	017	4	1.0	681202	QUOTA SERIAL NUMBER 825637
AUTOMT	036	4	1.0	681209	QUOTA SERIAL NUMBER 825638
HQMC	015	4	1.0		QUOTA SERIAL NUMBER 825687
B3000	025	7	1.0		QUOTA SERIAL NUMBER 825688
$MULT	.75				
S3531	100	7	1.0		QUOTA SERIAL NUMBER 825689
$MULT	.1				
S3531MA	100	5	1.0		QUOTA SERIAL NUMBER 825689
$MULT	.2				
S3531MB	100	5	1.0		QUOTA SERIAL NUMBER 825689
$MULT	1.05				
B0100A	018	6	1.0		QUOTA SERIAL NUMBER 825690
FMEADOS	030	5	1.0		QUOTA SERIAL NUMBER 825691
B0300A	904	6	1.0		QUOTA SERIAL NUMBER 825691
B0300A	894	6	1.0		QUOTA SERIAL NUMBER 825692
B0300A	025	6	1.0		QUOTA SERIAL NUMBER 825693
B0800A	100	6	1.0		QUOTA SERIAL NUMBER 825694
S0844A	057	6	1.0		QUOTA SERIAL NUMBER 825695
$MULT	.75				
S1371A	140	6	1.0		QUOTA SERIAL NUMBER 825696
$MULT	.1				
S1371AA	140	5	1.0		QUOTA SERIAL NUMBER 825696
$MULT	.2				
S1371AB	140	5	1.0		QUOTA SERIAL NUMBER 825696
$MULT	1.05				
B1300A	020	6	1.0		QUOTA SERIAL NUMBER 825697
B1800A	015	6	1.0		QUOTA SERIAL NUMBER 825698
B1800A	060	6	1.0		QUOTA SERIAL NUMBER 825699
S2511A	048	6	1.0		QUOTA SERIAL NUMBER 825700
S2532A	028	6	1.0		QUOTA SERIAL NUMBER 825701
B3000A	132	6	1.0		QUOTA SERIAL NUMBER 825702
B3300A	100	6	1.0		QUOTA SERIAL NUMBER 825703
$MULT	.75				
S3531A	099	6	1.0		QUOTA SER XL NUMBER 825704

Exhibit #17

QUOTA DISTRIBUTION REPORT PARRIS ISLAND 09/19/66 PAGE 10

PRIORITY GROUP	ASSIGN SYMBOL	EARLY BYDATE	LATE BYDATE	ORIGINAL QUOTA	REDUCED QUOTA	SHARE COEF.	PERCENT FILL
1	AGAVION	--	68/10/10	17	15	1,000	88,24
1	AGAVIONA	--	68/10/16	17	14	1,000	82,35
1	AGAVIONB	--	--	13	13	1,000	100,00
1	CTECHR	--	68/10/16	8	8	1,000	100,00
1	BEC	--	68/10/08	6	6	1,000	100,00
1	BEC A	--	68/10/15	8	8	1,000	100,00
1	BEC B	--	68/10/15	15	15	1,000	100,00
1	BEC C	--	68/10/22	15	15	1,000	100,00
1	BEC D	--	68/10/22	15	15	1,000	100,00
2	AGELECT	--	68/10/16	3	3	1,000	100,00
2	AGELECTA	--	68/10/23	3	3	1,000	100,00
2	AGELECTB	--	68/10/30	4	4	1,000	100,00
2	ARSCOB	--	68/10/23	5	5	1,000	100,00
2	FARAD	--	68/10/02	4	4	1,000	100,00
2	SHOFCOP	--	68/10/01	11	11	1,000	100,00
2	COMMCTR	--	68/10/02	8	8	1,000	100,00
3	AMPHIB	--	68/10/02	16	16	1,000	100,00
3	AMPHIB A	--	68/10/10	16	16	1,000	100,00
3	AMPHIB B	--	68/10/23	18	18	1,000	100,00
3	AMPHIB C	--	--	17	17	1,000	100,00
3	SPARTY	--	68/10/16	11	11	1,000	100,00
4	EMBAROP	--	68/10/01	8	8	1,000	100,00
4	REFRIG	--	68/10/10	6	6	1,000	100,00
4	ELECTR	--	68/10/22	9	9	1,000	100,00
4	EEOPR	--	68/10/08	8	8	1,000	100,00
4	EEOPR A	--	68/10/22	5	5	1,000	100,00
4	BSAC	--	68/10/02	9	9	1,000	100,00
4	BSAC A	--	68/10/10	11	11	1,000	100,00
4	BSAC B	--	68/10/10	11	11	1,000	100,00
4	BSAC C	--	68/10/16	11	11	1,000	100,00
4	BSAC D	--	68/10/16	11	11	1,000	100,00
4	BSAC E	--	68/10/22	11	11	1,000	100,00

Exhibit #18

SUPER QUOTA	ASSIGNMENT SYMBOLS				RELAXATION LEVEL	N	MEAN	SD	RELAXATION LEVEL	N	MEAN	SD	SUPER QUOTA GROUP N	MEAN	SD
30	EEOPR	A			1	5	111.6	10.3					5	111.6	10.3
31	AMPHIB				1	16	115.2	8.5					16	115.2	8.5
32	AMPHIB	A			1	16	118.7	8.6					16	118.7	8.6
33	AMPHIB	B			1	18	118.8	10.3					18	118.8	10.3
34	AMPHIB	C			1	17	118.2	9.0					17	118.2	9.0
35	SPARTY				1	11	120.7	9.5					11	120.7	9.5
36	CTECHR				1	4	131.8	10.4	2	4	139.3	7.7	8	135.5	9.4
37	COMMCTR				1	5	109.0	2.5	2	3	115.0	14.8	8	111.3	8.7
38	BEC				1	2	120.5	0.7	2	4	114.3	2.8	6	116.3	3.9
39	BEC	A	BEC	B	1	23	129.0	6.5					23	129.0	6.5
40	BEC	C	BEC	D	1	30	129.3	7.7					30	129.3	7.7
41	BSAC				1	9	118.9	10.8					9	118.9	10.8
42	BSAC	A	BSAC	B	1	22	117.2	9.1					22	117.2	9.1
43	BSAC	C	BSAC	D	1	22	121.5	8.2					22	121.5	8.2
44	BSAC	E			1	11	117.6	7.9					11	117.6	7.9
45	BSAC	F	BSAC	G	1	22	120.6	10.6					22	120.6	10.6
46	FREIGHT				1	11	106.4	5.7					11	106.4	5.7
47	CANWEB				1	2	95.5	3.5					2	95.5	3.5

Exhibit #19

FINAL DISTRIBUTION REPORT BY ASSIGNMENT SYMBOL PARRIS ISLAND 09/19/68 PAGE 16

ASSIGNMENT SYMBOL	PAGE NUMBER	SUPER QUOTA	MEAN	STANDARD DEVIATION	MEN ASSIGNED
AGELECT	13	1	126,33	7,57	3
AGELECTA	13	2	122,33	3,21	3
AGELECTB	13	3	119,00	3,56	4
AGAVION	13	4	118,33	6,84	15
AGAVIONA	13	5	121,57	7,23	14
AGAVIONB	13	6	126,31	8,47	13
AGADJR	13	7	99,00	6,32	6
AGADJR A	13	8	96,33	3,39	6
AGADJR B	13	9	116,83	6,11	6
AGAMAS	13	10	114,29	9,89	17
AGAMAS A	13	11	118,69	6,19	18
AGAMAS B	13	12	115,70	4,90	10
AGORD	13	13	116,00	4,86	6
AGORD A	13	14	122,17	12,24	6
AGORD B	13	15	115,50	7,78	2
AGAEROG	13	16	119,50	0,71	2
AVNCLER	13	17	100,50	15,02	4
AVNCLERA	13	18	104,00	7,81	3
AVNCLERB	13	19	115,83	4,67	6
AGAVCC			0,00	0,00	0
AGAVCC A			0,00	0,00	0
AIRSURV	13	22	117,63	8,65	8
EMBAROP	13	23	110,75	4,43	8
ARSCOB	13	24	132,00	8,57	5
FARAD	13	25	107,00	6,00	4
SHOFCOP	13	26	127,82	13,09	11
REFRIG	13	27	126,67	8,87	6
ELECTR	13	28	112,11	8,67	9
EEOPR	13	29	116,88	12,03	8
EEOPR A	14	30	111,60	10,31	5
AMPHIB	14	31	115,19	8,52	16
AMPHIB A	14	32	118,69	8,63	16
AMPHIB B	14	33	118,83	10,26	18
AMPHIB C	14	34	118,18	9,00	17

Exhibit #20

SUMMARY INFORMATION PARRIS ISLAND 09/19/68 PAGE 18

TOTAL MEN ASSIGNED = 3505

TOTAL MEAN PAYOFF = 110,850

TOTAL RELAXATIONS = 29

TOTAL LEVELS = 101

Exhibit #21

DOD_OCCUPATIONAL_GROUP_ASSIGNMENT_SUMMARY PARRIS_ISLAND 09/23/68 PAGE 1

DOD OCC GROUP	MOS		MENTAL GROUP 1	MENTAL GROUP 2	MENTAL GROUP 3	MENTAL GROUP 4-A	MENTAL GROUP 4-B	COLLEGE GRAD.	UNKNOWN	TOTAL
8	0300	COUNT	56	462	980	320	117	2	10	1947
		ROW %	2,88 %	23,73 %	50,33 %	16,44 %	6,01 %	0,10 %	0,51 %	100,00 %
		COL %	42,75 %	54,35 %	56,94 %	53,42 %	40,07 %	11,11 %	32,26 %	53,46 %
		TOT %	1,54 %	12,69 %	26,91 %	8,79 %	3,21 %	0,05 %	0,27 %	53,46 %
	0800	COUNT	4	25	45	19	12	0	0	105
		ROW %	3,81 %	23,81 %	42,86 %	18,10 %	11,43 %	0,00 %	0,00 %	100,00 %
		COL %	3,05 %	2,94 %	2,61 %	3,17 %	4,11 %	0,00 %	0,00 %	2,88 %
		TOT %	0,11 %	0,69 %	1,24 %	0,52 %	0,33 %	0,00 %	0,00 %	2,88 %
	0844	COUNT	0	25	34	1	0	3	0	63
		ROW %	0,00 %	39,68 %	53,97 %	1,59 %	0,00 %	4,76 %	0,00 %	100,00 %
		COL %	0,00 %	2,94 %	1,98 %	0,17 %	0,00 %	16,67 %	0,00 %	1,73 %
		TOT %	0,00 %	0,69 %	0,93 %	0,03 %	0,00 %	0,08 %	0,00 %	1,73 %
	0846	COUNT	1	3	1	0	0	0	0	5
		ROW %	20,00 %	60,00 %	20,00 %	0,00 %	0,00 %	0,00 %	0,00 %	100,00 %
		COL %	0,76 %	0,35 %	0,06 %	0,00 %	0,00 %	0,00 %	0,00 %	0,14 %
		TOT %	0,03 %	0,08 %	0,03 %	0,00 %	0,00 %	0,00 %	0,00 %	0,14 %
	0849	COUNT	1	6	4	0	0	0	0	11
		ROW %	9,09 %	54,55 %	36,36 %	0,00 %	0,00 %	0,00 %	0,00 %	100,00 %
		COL %	0,76 %	0,71 %	0,23 %	0,00 %	0,00 %	0,00 %	0,00 %	0,30 %
		TOT %	0,03 %	0,16 %	0,11 %	0,00 %	0,00 %	0,00 %	0,00 %	0,30 %
	1300	COUNT	1	4	5	8	2	0	1	21
		ROW %	4,76 %	19,05 %	23,81 %	38,10 %	9,52 %	0,00 %	4,76 %	100,00 %
		COL %	0,76 %	0,47 %	0,29 %	1,34 %	0,68 %	0,00 %	3,23 %	0,58 %
		TOT %	0,03 %	0,11 %	0,14 %	0,22 %	0,05 %	0,00 %	0,03 %	0,58 %
	1371	COUNT	4	14	52	47	55	0	5	177
		ROW %	2,26 %	7,91 %	29,38 %	26,55 %	31,07 %	0,00 %	2,82 %	100,00 %
		COL %	3,05 %	1,65 %	3,02 %	7,85 %	18,84 %	0,00 %	16,13 %	4,86 %
		TOT %	0,11 %	0,38 %	1,43 %	1,29 %	1,51 %	0,00 %	0,14 %	4,86 %
	1800	COUNT	4	12	31	25	5	0	2	79
		ROW %	5,06 %	15,19 %	39,24 %	31,65 %	6,33 %	0,00 %	2,53 %	100,00 %
		COL %	3,05 %	1,41 %	1,80 %	4,17 %	1,71 %	0,00 %	6,45 %	2,17 %
		TOT %	0,11 %	0,33 %	0,85 %	0,69 %	0,14 %	0,00 %	0,05 %	2,17 %
GROUP TOTAL		COUNT	71	551	1152	420	191	5	18	2408
		ROW %	2,95 %	22,88 %	47,84 %	17,44 %	7,93 %	0,21 %	0,75 %	100,00 %
		COL %	54,20 %	64,82 %	66,94 %	70,12 %	65,41 %	27,78 %	58,06 %	66,12 %
		TOT %	1,95 %	15,13 %	31,63 %	11,53 %	5,24 %	0,14 %	0,49 %	66,12 %

Exhibit #22

5() 000 PI ASSIGN 01091968 000000000000000000000000000000000000000000000

	QUOTA SERIAL NUMBER 825643					AGAVIONA	1	5
MCCARTHY	GWAQQ1D244859860	B	5H	20QQ	6500108123121123126118111113A10	AGAVIONA		5
BANTT	JRAQQ1D243561064	B	5H	21QQ	650011912511711712611712410 8A11	AGAVIONA		5
BOOZER	HWTQQ1D243558562	A	5A	22QQ	65001131181211181171051211 02B00	AGAVIONA		5
GREEN	RETQQ1D245561667	A	5A	19QQ	65001391301311391281082514 5B00	AGAVIONA		5
PADGET	CTAQQ1D243560862	B	5H	20QQ	6500114126116123128089118118B00	AGAVIONA		5
THORNBURG	RSTQQ1D243551867	A	5C	23QQ	6500135128120125120118127124B00	AGAVIONA		5
HICKENS	JLTQQ1D245544167	C	5H	20QQ	650009110912911410610311310 8B01	AGAVIONA		5
SANTOS	DCAQQ1D239329363	B	5H	18QQ	6500112115127123116109114117B01	AGAVIONA		5
MADDEN	STAQQ1D242921960	A	5H	18QQ	65001401221371221191121290 99B03	AGAVIONA		5
WILSON	PEAQQ1D247697760	B	5H	18QQ	6500137117110124121108113111B04	AGAVIONA		5
DIMARZO	FCAQQ1D244852266	B	5H	20QQ	65001341331271411461151320 98C03	AGAVIONA		5
ENRIQUEZ	M AQQ1D249158162	B	5A	19NQ	6500128124111108111129117107C03	AGAVIONA		5
WEBSTER	RGAQQ1D244847268	A	5H	20QQ	650012413013514013412213114 0C03	AGAVIONA		5
KEENAN	TJTQQ1D244595569	C	5H	19QQ	65001241081201131081151270 77C04	AGAVIONA		5
	QUOTA SERIAL NUMBER 825644					AGAVIONB	1	6
COLEY	CAAQQ1D240946963	B	6H	20QQ	65001261311221231211141231 23A15	AGAVIONB		6
FROHAN	DRTQQ1D246032558	A	6H	20QQ	65001241131301091121061191 39A15	AGAVIONB		6
NAPIERKOWSKI	SATQQ1D246419064	20D	6B	20NQ	6500096118105101104120125111B13	AGAVIONB		6
SCIUKAS	VPAQQ1D247462064	B	6H	18QQ	65000941181131221151051241 30C12	AGAVIONB		6
SCURLOCK	AGTQQ1D248605369	B	6A	21QQ	65001331121331251131161320 73C12	AGAVIONB		6
WALTERS	ECTQQ1D247465967	A	6H	20QQ	65001241261271141221151291 27C12	AGAVIONB		6
WILLIS	GLTQQ1D246040780	A	6C	21QQ	65001441111251231071131451 23C12	AGAVIONB		6
CARR	JR QQ1D248609660	B	6-	20QQ	65001071251111101141171241 15C13	AGAVIONB		6
GERMENO	DATQQ1D244857767	B	6A	21QQ	65001241221331291241151311 26C13	AGAVIONB		6
MARTIN	GSAQQ1D246005369	B	6H	18NQ	65001141261141171261211291 30C13	AGAVIONB		6
DEMNYAN	JA QQ1D244611660	B	6H	20QQ	65000821091221151051221111 30C15	AGAVIONB		6
MCCLENDON	JHAQQ1D246036560	C	6H	20QQ	65001141171261261341201170 80C15	AGAVIONB		6
MURPHY	EPTQQ1D245254169	A	6H	19QQ	65001291241351401321231330 93C15	AGAVIONB		6
	QUOTA SERIAL NUMBER 825645					AGADJR	1	7
WALLACE	RE NN1D2452491	D	7H	20QQ	65001041091021021010890900 67A01	AGADJR		7
OKESON	FWANN1D2455277	D	7H	19NQ	65000931000808808908409106 0A05	AGADJR		7
METTLE	JEAQN1D225541458	C	7H	18NQ	6500117080110104092113113106C01	AGADJR		7

Exhibit #23

RECRUIT ASSIGNMENT CARD FORMATS

SAN DIEGO

Card columns	Description
1-11	Name
12-13	Initials
14-20	Service number
21	Component
22	Obligation
23	School subject (algebra or trigonometry)
24-25	Age
26	Education
27-30	Platoon number
31	EDPT
32	ALAT
33-56	Area aptitude scores: IN 33-35, AE 36-38, EL 39-41, GM 42-44, MM 45-47, CL 48-50, GT 51-53, and RC 54-56
57-58	Typing
59-60	ETST
61	Visual acuity
62	Color perception
63	Flight crew/Jump volunteer
64	Citizenship
65	Mental group
66	1st high AA
67-70	Avia. and Cat. II MOS
71	Height
72-74	Super-quota number
75-80	---blank---

PARRIS ISLAND

Card columns	Description
1-12	Name
13-14	Initials
15	School subject (algebra or trigonometry)
16	VE 100+
17	AR 100+
18	Component
19	Obligation
20-26	Service number
27-28	ETST
29-30	Typing
31	Mental group
32-34	Super-quota number
35	Education
36-39	---blank---
40-41	Age
42	PA 105+
43	Citizenship
44-49	---blank---
50-53	Avia. and Cat. II MOS
54-77	Area aptitude scores: IN 54-56, AE 57-59, EL 60-62, GM 63-65, MM 66-68, CL 69-71, GT 72-74, and RC 75-77
78-80	Platoon number

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Unclassified
Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY (Corporate author) DECISION SYSTEMS ASSOCIATES, INC. 11428 Rockville Pike Rockville, Maryland 20852	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

COBRA: UNITED STATES MARINE CORPS COMPUTER-BASED RECRUIT ASSIGNMENT MODEL

4. DESCRIPTIVE NOTES (Type of report and inclusive dates)

Final Technical Report and User's Guide

5. AUTHOR(S) (First name, middle initial, last name)

HATCH, RICHARD S.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
June 1969	75	39

8a. CONTRACT OR GRANT NO. Nonr-4070(00) b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) None 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)

10. DISTRIBUTION STATEMENT

Qualified requesters may obtain copies of this report from DDC.

11. SUPPLEMENTARY NOTES None	12. SPONSORING MILITARY ACTIVITY Commandant, USMC Headquarters, U.S. Marine Corps (Code A01B) Washington, D.C.

13. ABSTRACT

The purpose of this research project was to develop a completely automated recruit assignment model for the United States Marine Corps. Research was required to develop mathematical algorithms capable of arriving at optimal solutions to multi-million cell matrices in reasonable computer times. After reviewing the literature and testing a number of published algorithms, it was determined that extensive modifications of the Ford-Fulkerson primal-dual network flow algorithms provided the most efficient approach. A non-linear optimization technique was developed and incorporated with the maximum flow algorithm to provide precise control over the resolution of infeasible problems. The technique employs the method of LaGrange multipliers and Newton-Raphson iterations to share shortages fairly over assignment categories of equal importance and unfairly over assignment categories of unequal importance. Another important algorithm was designed to handle optimization of multiple, usually conflicting, assignment policies. After design of the basic algorithms, a large, single-submission system (COBRA) was designed and programmed for the CDC 3600 computer.

An evaluation of the system was carried out. Solutions derived from manual assignment procedures, operational at the time, were compared with solutions generated by the COBRA system for the same data. For each of seven months' parallel assignment outcomes, the COBRA system provided substantially superior assignment solutions: closer adherence to desirable assignment objectives and a considerably higher average estimate of performance for recruits in schools to which they were assigned. The COBRA system was then implemented by the contractor at Headquarters U.S. Marine Corps in the Spring of 1965. This document provides, in addition to final report of the research project, sufficient user information to understand and operate the system.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

Unclassified
Security Classification

A-31408

Unclassified
Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Allocation						
Assignment problem						
Computer-based model						
Linear programming						
Manpower management						
Multiple objective optimization						
Network flow problem						
Non-linear optimization						
Optimization						
Personnel Assignment						

DD FORM 1 NOV 65 1473 (BACK)
S/N 0101-807-6821

Unclassified
Security Classification

A-31409